DSL Anywhere:

A paper designed to provide options for Service Providers To extend the reach of DSL into previously un-served areas

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1.0 Introduction

Digital Subscriber Line (DSL) service is in high demand from the user community. However, a significant portion of the general user community cannot get DSL service because they are either located at too great a distance from the service provider's Central Office (CO) or they are not served directly by a metallic loop. This paper offers architectural solutions and techniques for extending DSL coverage to help service providers deploy "DSL Anywhere."

1.1 Scope

This release of this DSL Anywhere paper is targeted primarily toward service providers in the United States. Many of the aspects discussed in this paper may also apply to other countries, depending on the regulatory and infrastructure environment specific to each country. The term "DSL Anywhere" refers to DSL Forum's initiative to encourage service providers to seek methods and solutions that greatly expand DSL availability to as many subscribers as possible. The intent of this initiative is to also encourage industry vendors to continue to innovate to provide efficient and cost effective solutions that enable viable business cases, allowing service providers to significantly extend DSL availability. The methods and solutions described in this paper are some of the most recent and potential options that are available to service providers.

Availability of DSL is just one metric that service providers need to consider. Service provider need to consider the target applications and the required data rates for each application. As a result, DSL deployment models should be considered which significantly shorten the loop distance to the subscriber. For example, it may be viable to serve subscribers up to 17K feet with 384Kbps service for Internet access. However, some service providers plan to provide services that need guaranteed data rates of at least 1.5Mbps, requiring the target serving area to be within 12Kft. Even shorter subscriber loops may be required for the delivery of video and other high bandwidth services.

In summary, this DSL Anywhere paper attempts to provide insights to some of the different method and solutions currently available. While the term "DSL Anywhere" is the goal, we do not pretend that the options identified within will achieve 100% market coverage. We do hope that these options (and others) will significantly close the gap between the projected availability of DSL and the large number of subscribers that wish to subscribe to DSL service.

1.2 The Situation

At the end of 2000, there were approximately 200 million fixed access lines installed in the U.S. Of these 200 million lines, about 35%[1] are served from Remote Terminals (RTs) with the other 130 million lines (65%) served from central offices. To date the vast majority of remote DLC lines are narrowband and are not equipped to support DSL. In addition, although DSLAMs have been widely deployed in central offices, not all subscribers served from central offices are eligible for DSL as carriers typically limit their

[1] RHK 2000 Access Network System Market Forecast, February 29, 2000

DSL footprint based on the distance between the home and the loop termination in the network. For example, to achieve minimum ADSL data rates of 384Kbps downstream and 128Kbps upstream, service providers typically limit DSL deployment to the approximately 180 million lines (90% of all lines) that are within 17,000 feet of the central office.

Similarly, to guarantee optimal data rates of 1.5 Mbps downstream, carriers will typically limit DSL service to the approximately 100 million lines (50%[2]) that are within 12,000 feet of the central office or remote terminal. In addition, due to economic constraints, many service providers have elected not to invest in equipping DSLAM or DSL equipment in as many as 20% of their central offices, which serve more rural and less profitable subscribers. The net result is that given the present deployment models, DSL can be provided to less than 50% of all subscribers, with the remaining 100 million subscribers ineligible to receive DSL. Based on currently announced deployment plans it is expected that the DSL eligible footprint will grow to about 70% of subscribers by 2004.[3]

The popularity of the Internet has resulted in a seemingly insatiable appetite for high-speed local access to relieve the “World Wide Wait” that has resulted from standard local loop and switching bottlenecks. Asymmetric Digital Subscriber Line (ADSL) is an advanced modem technology that utilizes different frequency spectrums to simultaneously transmit high-speed voice and data over the same copper loop. ADSL has been effectively shown to meet the demands for high speed Internet access without the deployment of new loop plant. However, two serious hurdles remain to be overcome before ADSL services can be made available to the greater user community.

- **Distance limitations -** Unlike lower speed modems that can be connected to long local loops, ADSL modems are generally ineffective over the longer local loops. The achievable reach is dependent on the transmission rate.

- **Incompatible DLCs -** ADSL service has generally been provided over home run copper loops. Digital Loop Carriers (DLCs) are being employed at an increasing rate as a cost-effective alternative to long copper loops and can interfere with ADSL service. A DLC provides a high-speed link between the CO and the DLC Remote Terminal (RT) with a copper pair extending from the RT to the customer premise. While the latest DLC products can support ADSL service, many installed DLCs do not.

1.3 Market Requirements for Extending DSL Service

For the past 100 years, POTS (Plain Old Telephone Service) has been the foundation (volume service) of the public telephony access network. DSL is now emerging with the promise to become a volume service as well, but service providers must first be able to make DSL as ubiquitous and affordable to subscribers as POTS service is today.

Today's DSL network infrastructure has been designed as an overlay to the TDM voice network. Although overlay networks may be effective for the delivery of specialized enterprise services, they are not generally scalable for consumer mass-market

[2] RHK 2001 North American XDSL Market Forecast, February 21, 2001
[3] RHK 2001 North American XDSL Market Forecast, February 21, 2001

deployment. The overlay architectures do not enable service providers to realize cost efficiencies from the integration of their volume voice and DSL operations and, thereby, achieve high-volume, mass-market deployment. For service providers to successfully deploy “DSL Anywhere,” they will require network solutions that can address the following major network trends:

- **Consumer demand for DSL service is not being met -** Service providers are equipping Central Offices and deploying DSL service as quickly as they can. According to Telechoice[4], approximately 2.1 M DSL subscribers in North America were in service by year-end 2000. However, the vast majority of subscribers are still unable to get DSL. This is either because they do not qualify (subscriber serving area or specific line is not DSL ready), or because they are waiting in a service provider’s backlog, as deployment fails to keep pace with demand.

Solutions to enable "DSL Anywhere" must enable rapid deployment and provisioning and must be highly scalable to meet the current and growing demand.

- **The majority of subscribers will be served from Remote Terminals -** According to the market research firm RHK[5], the installed base of Digital Loop Carrier (DLC) Remote Terminals (RTs) serves about 35% of the loops deployed in today’s network. Service providers are currently deploying more than 60% of new lines from RTs, and RHK predicts that within 3 years, more than 50% of all subscribers in the U.S. will be served from RTs. Network trends indicate that service providers will continue to deploy fiber closer to subscribers and the RTs will become the Central Office of the future.

Solutions to enable "DSL Anywhere" must solve the current difficulties associated with volume DSL deployment from remote terminals.

- **Service providers will migrate to a converged, packet-based network for the delivery of voice and data services -** The growth of the Internet has resulted in data traffic exceeding the volume of voice traffic on today’s Time Division Multiplexed (TDM) Public Switched Telephone Network (PSTN). Service providers have been forced to significantly grow the capacity of their TDM networks to accommodate the long hold times from data calls, without the benefit of incremental revenue. As a result, service providers are putting plans in place to displace the legacy TDM switch infrastructure with a new converged, packet-based network — a single network infrastructure for delivering integrated voice/data services[6].

Solutions to enable "DSL Anywhere" must enable service providers to migrate gracefully to a converged, packet-based network.

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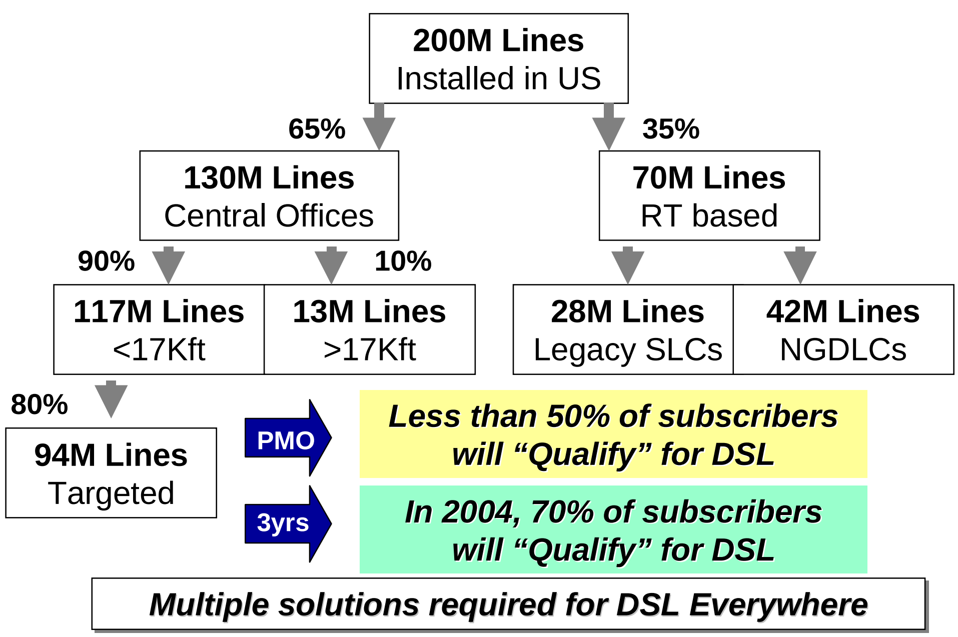
[4] Telechoice DSL Deployment Summary – Updated 8/9/00
http://www.xdsl.com/content/resources/deployment_info.asp
[5] RHK 2000 Access Network System Market Forecast, February 29, 2000
[6] Trend based on meetings with several service providers

1.4 DSL Anywhere Analysis

The demand for high-speed access and the technology adoption of DSL has been unprecedented in the telecom industry. The deployment of DSL has grown exponentially from an installed base of fewer than 500,000 lines to well over 2 million lines in a single year.[7] While DSL industry growth rates are impressive, DSL still has only been deployed on slightly more than 1% of the installed base of subscriber lines in the U.S. However, all market indicators and analysts' forecasts suggest that DSL demand will continue to grow at a staggering rate. Driving the bandwidth demand is the increasing consumer appetite for rich Internet content, including multimedia and peer-to-peer file-sharing programs as well as the trend to increased telecommuting and the requisite need for access to company VPNs and e-mail servers. As a result, service providers must implement cost-effective and scalable DSL product solutions that optimize operations and speed the velocity of DSL service deployment.

While most service providers have deployed DSLAMs to the majority of their central offices, nearly 100 million subscribers who may wish to have high-speed access are still not eligible due to a number of hurdles, the most significant being DSL distance limitations. However, carriers now have the option to explore a number of avenues to address these ineligible customers, including deployment of broadband capable remote terminals (RTs), emerging technologies such as loop extenders and repeaters, and scalable methods for automatic and remote provisioning.

Present Course for DSL Availability



[7] Robertson Stephens, Next Generation Networks – DSL Market: Demand doesn't seem to be an issue, but Carrier deployment execution does; re-evaluating the DSL sector, January 3, 2001

The intent of this DSL Anywhere white paper is to help service providers identify a number of different DSL solutions that enable cost-effective and efficient deployment of DSL Anywhere. When selecting the appropriate DSL method or solution, service providers should carefully consider the application, the required data rates, the anticipated DSL penetration and the evolution plans of their network (such as the convergence of voice and data). Some carriers have publicly announced plans to shorten loops to 12,000 feet by the deployment of neighborhood gateways (Next Generation Digital Loop Carriers and Broadband Loop Carriers). This would improve their operational costs and improve their data rate offerings to support up to 1.5Mbps network-wide (and data rates up to 6Mbps for as many as 60%[8] of those subscribers). Initiatives such as SBC's Project Pronto[9] will significantly increase the availability of DSL by deploying new broadband-equipped Remote Terminals and upgrading existing RTs with DSL. In addition to RT-based DSL solutions, there are a number of other methods and solutions that enable service providers to rapidly and cost-effectively deploy DSL Anywhere. The following table summarizes the methods and solutions, which support various DSL deployment applications.

		Central Office				Remote Terminal					
Addressable Market	200M addressable lines	94M lines	71M lines	26M lines	21M lines	20M lines	8-28M lines	42M lines	14M lines	6M lines/yr	0-200M lines
	Solution	DSL Targeted COs <17K	DSL Targeted COs <12K	COs >17Kft	Untargeted COs	SLC Upgrade	SLC Replacement	NGDLC Upgrade	Sym Bus. Svcs	New Growth	Softswitch - Convergence
Overlay	DSLAM	X	X		X					X	
	R-DSLAM					X		X			
	Mini-RAM					X		X			
Integrated	DLC Linecard					X		X			
	NGDLC						X			X	X
	BLC	X	X		X		X			X	X
Repeater	Loop Ext. Repeater			X							
New Technology	G.SHDSL								X		
	Improved DSL			X	X						
Alternative Solutions	Low Frequency DSL			X	X						

Table 1: DSL Anywhere solutions for different deployment applications

Table 1 illustrates that service providers can significantly increase their DSL service coverage, improve their data-rate offerings and reduce their costs by appropriately selecting the DSL method or solution that best fits their deployment application. For example, a service provider could choose to use central office DSLAMs to serve CO-fed subscribers that are within 12,000 feet, upgrade their existing installed base of legacy Subscriber Loop Carriers (SLCs) and NGDLCs with integrated POTS+DSL line cards, and deploy NGDLCs and/or Broadband Loop Carriers for new growth. This DSL deployment strategy would dramatically improve DSL availability to nearly all but the subscribers that are beyond 17,000 feet. The service provider can use "new technologies," such as Improved DSL and Low Frequency DSL to address these remaining subscribers.

[8] SBC Project Pronto, http://www.sbc.com/data/network/0,2951,5,00.html
[9] SBC Project Pronto, http://www.sbc.com/data/network/0,2951,5,00.html

2.0 Loop Qualification Techniques

Since DSL technologies are not able to operate on some loops due to excessive loop length, excessive bridged taps, and other factors, it is necessary to determine which loops can support DSL service; this is know as *loop qualification*. Loop qualification often involves some degree of estimation. In the past, techniques such as measuring the straight-line distance from the CO to the customer on a map resulted in estimates of poor accuracy. The poor estimates for loop qualification resulted in service providers not attempting to provide service to fringe-area customers who actually could have been reliably served, and also resulted in attempts to provide service on loops that could not support the service. This section discusses the adoption of new loop qualification techniques that greatly improve the accuracy of the estimates, resulting in service being provided to customers who would have previously not qualified, and reducing the number of frustrating cases of failed turn-up. As a result, DSL services become available to more customers, and the cost to provide service is reduced. A future DSL Forum paper is expected to address loop qualification and loop management in greater depth.

There are two approaches to loop qualification: 1) on-demand qualification, and 2) pre-qualification. With on-demand qualification, when a customer calls the service provider to request service, the service representative then initiates an analysis of the loop connected to that customer. This may involve an engineer to analyze the loop characteristics stored in a database, technicians performing measurement with test-equipment, or ideally the service representative have direct access to a CO-based loop test system that can immediately test any loop. Due to the generally high costs and slow response for on-demand qualification, service providers have widely adopted pre-qualification. With pre-qualification, every loop connected to a CO is analyzed in advance of customer orders The critical first step to achieve mass market DSL deployment is loop pre-qualification of a target market. Once loop pre-qualification of a target market area is complete, the service provider is now positioned to begin effective mass deployment of DSL services, which includes the following:

- Ensure that DSL services can be deployed to the target market area
- Ensure that the subscriber loops supports the bandwidth required for the target service applications
- Eliminate Truck Roll
- Minimize human intervention
- Provide the ability to enable subscribers to self install CPE
- Enable flow through provisioning

This section addresses the process and techniques used for loop qualification.

2.1 Loop Qualification

Loop pre-qualification testing is normally performed prior to the initialization or turn-up of an xDSL service or circuit. It should be the first of many possible test actions taken to ensure end-to-end connectivity and throughput is possible. Although true performance testing cannot be done until Customer and Provider equipment have been provisioned and brought on line, much can be done to ensure the likelihood of a positive turn-up experience by confirming the condition of the loop. Loop qualification testing is most cost-effectively and practically done if it is performed from centralized locations without the need to reconfigure existing services and dispatch technicians. The loop qualification process should be automated to make it more efficient. A comprehensive testing solution should also have the ability to quickly identify xDSL circuit problems as inside or outside plant facilities or equipment problems. The system should be capable of providing suggestions as to the nature of the problem(s) and steps necessary to further isolate or resolve the problem(s), as well as support storage, benchmarking, and comparison functions that are applicable to this information. This is especially true as xDSL Providers attempt to ramp-up their deployments to scale. To qualify large numbers of copper pairs, automated bulk testing under the control of an Operational Support System (OSS) is highly desirable. In addition to automated bulk qualification testing, a system supporting on-demand or pass-through loop qualification is also very helpful. The on-demand loop qualification allows a user to quickly perform a test for a circuit that may not yet have been qualified or to reapply the test to confirm the state of a circuit. There are a few situations where automated, flow-through, testing is not practical, and in those cases portable devices are used by technicians to pre-qualify loops one-by-one as customers request xDSL service.

Loop qualification is the process of determining if the copper loops connected to the customer’s home or office, sometimes referred to as the Premises, or “Prem”, have physical impairments that would prevent or inhibit xDSL transmission. Common physical impairments that prevent or inhibit xDSL transmissions are excessive loop length; the presence of loading coils; excessive bridged taps or other physical wiring issues like shorts, opens, crossed pairs, etc.; and significant crosstalk or other noise. These will be discussed in depth below. But first, a copper loop backdrop:

The loop usually connects the LEC’s Central Office (CO) to the Customer Prem, using combinations of 24GA or 26GA wire that can span a wide range of distances, up to several miles. In other cases, the copper loop connects the Prem to an intermediate location like an undergound Controlled Environmental Vault (CEV) or an above ground metal cabinet called a pedestal or Remote Terminal, where it is electronically grouped with other loops in the immediate area and brought back to the CO over Subscriber Loop Carrier (SLC) or Digital Loop Carrier (DLC) systems. This method is used to extend network access to distant service areas that would otherwise be unreachable. In cases where the equipment used to provide the service and test it will be exposed to the elements, it is crucial that the hardware used is environmentally hardened in order to weather these adverse environmental conditions.

Testing:

***Loop Length* -** The length of the loop is a factor because, even if the loop does not contain shorts, opens, or even bridged taps, the wire itself has loss. The longer the loop is, the more loss, resulting in lower transmission rates. The achievable xDSL transmission rate is inversely proportional to the loop length, so it is imperative to know the loop length in able to establish the flavors and rates of service that could be supported by the loop. Single-ended capacitive measurements can provide a quick, accurate, and low cost determination of total loop length, including bridged tap that is discussed below. Loop length can also be determined using a resistance measurement, but this method is rarely used since it requires a technician's assistance to insert a short across the tip and ring at the Prem. Better yet, should a costly technician dispatch be made to pre-qualify the line, an end-to-end loss measurement using xDSL specific tones would provide a direct indication of the loss, which would be preferred over the indirect loss calculation derived from a loop length measurement.

Loading Coils - Loading coils are in-line inductors used as low pass filters to balance the response of the loop for voice frequency transmission. These devices effectively block xDSL signals. As a general rule they exist on any loop greater than 18,000 feet. However, these DSL-killers are not limited to long loops. Why? Over time, some of these long loops have been shortened as intermediate loop carrier systems were introduced. Unfortunately, in many cases the loading coils were not removed from the remaining loop sections. All of the loading coils on the prospective circuit must be detected and removed. A testing device is required to be able to detect at least the first loading coil on the loop and its location. Facilities maintenance crews assigned to remove the loading coil will check for the presence of additional coils as part of their normal troubleshooting method or procedure.

Bridged Taps - Bridged taps are lengths of open wire that are connected in parallel with the loop being evaluated. Bridged taps are typically formed when changes are made to the loop that leaves unneeded cable attached to the loop. Bridged taps can exist between the CO and the customer premise, or it can extend beyond the customer. The negative effect of these bridged taps on xDSL service is directly related to the location, length, and gauge (size) of the wire; the type of xDSL service being deployed; and the frequencies used by the service. Some amount of bridged tap may be tolerated, depending on the location of the tap and the flavor of service that will be operated over the loop.

A testing device is required to detect the length and location of the bridged taps. A Time Domain Reflectometer (TDR) is one of many test devices available to determine the location and length of bridged taps with any degree of effectiveness. Short and open circuits, and loading coils, can be located using the TDR as well. However, to the untrained eye TDR traces can be difficult to interpret. So, having a TDR that includes built-in expert analysis software is key to minimizing training requirements and offsetting high turnover problems. Since the “expert” is in the test head, the technician executing the test merely engages the tools and reads the test results.

Crosstalk and Noise - Long stretches of cable running side by side with other cabling are susceptible to crosstalk. The extent to which crosstalk is a problem is dependent on many factors, some of which are the number, strength and type of the crosstalk sources, the susceptibility of the crosstalk receiver loop, the distance that separates the sources from the receiver, and the extent to which the source frequencies and their harmonics overlap the receiver transmission frequencies. When these crosstalk sources, otherwise known as "interferers" or "disturbers," combine with other noise sources the effective noise floor can be raised to the point where the transmission of the loop is slowed down or even halted.

These noise sources, and their effects on the xDSL transmission, can be visually observed using a spectrum analyzer. As with the TDR, the spectrum analyzer can provide a great deal of information to the trained eye. Absent that training, systems having built-in expert analysis are critical to determining when and where interferers exist so the loop can be turned over to maintenance for repair and the interferers can be removed.

2.1.2 Loop Qualification Justification

In most cases, the question of loop qualification is not whether to perform the testing or not. More often it is a cost trade-off decision between the test benefits versus the cost of testing.

Within the Plain Old Telephone Service (POTS) arena, test access has most often been provided through a test interface to the voice switch, commonly referred to as the "No. Test Trunk" or "NTT". This access is sometimes available in North American voice switches and in a similar form in many international switches. Existing metallic loop test systems use this access method. Unfortunately, these test conduits are frequency constrained and do not pass much of the bandwidth used for xDSL services.

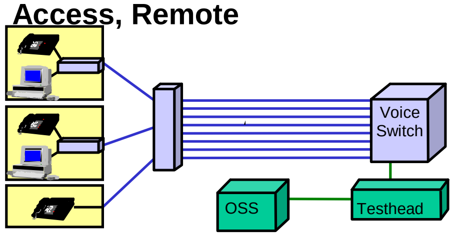
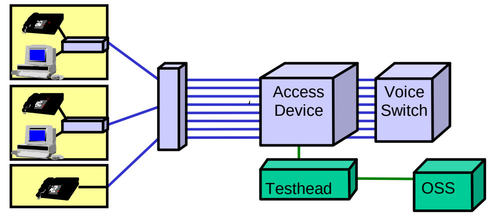
Because of this frequency boundary, the NTT access cannot be used to conclusively predict xDSL loop performance, although some testing is possible. Some of the tests from the list above - namely loop length and loading coil detection - can be performed using the NTT access. Another useful test that can be accomplished through the narrow NTT portal is loop balance, which is an indicator of the degree to which the loop would be receptive to crosstalk, if it were exposed.

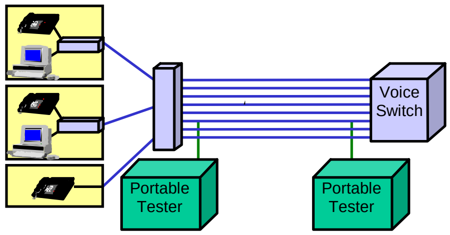
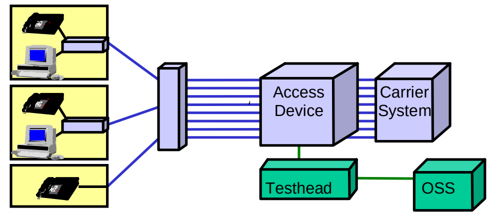
Narrowband testing is a necessary step, but does not completely satisfy the requirements for loop qualification. Wideband testing is required to fully test the loop's capacity to carry DSL services.

In the table that follows, the typical loop qualification approaches have been separated into categories that relate to:

- Where the loops terminate - either central office (**CO**), or remote terminal (**RT**),
- Where the access is made - either via the **Switch** (NTT), or directly accessing the **Loop** (via a Metallic Test Access Unit (MTAU), or directly in the case of portable testers) and,
- Where the testing is performed - either from a **Remote** location using network-based operating systems, or **On-Site** using one or more portable testers.

The advantages and issues relating to each loop qualification approach are addressed in a bullet format. These should be used as general indicators of which approach would apply, given the provider's operational and network environment.

Description	**CO Based, Voice Switch Access, Remote**  	**CO Based, Loop Access, Remote** 
Advantages	• Uses existing test trunk access • Some provide rate estimate • Test data benchmarking possible	• Unobstructed wideband test access • Some provide rate estimate • Test data benchmarking possible • • Can be used afterward for maintenance support
Implementation, Deployment Issues	• Minimal - requires test head and an appropriate driver • Switch must be equipped with an available test port • • Loop must terminate at switch	• Requires test head and loop access device
Operational Issues	• Due to NTT frequency constraints, cannot detect wideband disturbers • Limited ability to detect bridged taps	•

Description	CO & RT Based, Loop Access, On-Site	RT Based, Loop Access, Remote
		
Advantages	• Two-ended testing provides most accurate wideband test results • Some provide rate estimate • Test data benchmarking possible	• Unobstructed wideband test access • Some provide rate estimate • Test data benchmarking possible • Limited truck rolls after initial setup • Capable of addressing follow-on maintenance test requirements
Implementation & Deployment Issues	• Test hardware management - Mass deployment results in requirement for large number of test sets - normally two needed per test	• Requires environmentally hardened test head and may require loop access if built-in access is not available • Limited Provider space • Communications link required
Operational Issues	• Requires truck roll • Customer scheduling • Significant training requirement for both field and CO techs • Coordination between CO and field techs required • Test result storage and transmission difficult • No long-term loop monitoring (disturber detection) growth potential	• Some test access hardware already in place • Test access is required

3.0 Overlay Access Solutions

Overlay access solutions describes systems that provide DSL service on top of existing POTS equipment in the remote space. Traditional POTS gear is generally referred to as remote terminal (RT) gear. Since much of this legacy gear does not have the architectural bandwidth to provide DSL service, overlay solutions are beneficial when one doesn't wish to replace the existing POTS equipment.

Overlay solutions include central office DSLAMs (DSL Access Multiplexers), Remote DSLAMs and RAMs. The Remote DSLAM is essentially just an ordinary CO DSLAM, except it must be industrially hardened. This means that is must operate in conditions from -40 degrees Celsius to +65 degrees Celsius and meet a stringent set of requirements for operation in the remote environment. Additionally, requirements for front panel access and remote configuration are important.

The Remote Access Multiplexer (RAM) products are super-low-profile products, which are designed to fit into nearly any DLC. The RAMs are generally between 1U and 3U in vertical size, and can generally fit into DLC cabinets that are already "full" of POTS equipment. This is highly desirable when the service provider wishes to provide DSL service, has little room in the cabinet for a DSLAM, and doesn't wish to expend the cost of new POTS equipment or adjunct cabinetry.

3.1 Remote Access Multiplexer

The Remote Access Multiplexer (RAM) is perhaps the stealthiest DSLAM device. . Because of their small size and relatively small cost, they are quick and easy to deploy and often serve as excellent competitive tools against cable modem deployments, since DSL service providers can use them to target neighborhoods where cable modem services are being deployed. Today, many thousands of RAMs are deployed in many networks across the world.

RAM products are DSL devices, which can be deployed in the remote terminal/DLC environment. The unit is industrially hardened and typically supports ambient temperatures of -40C to +65C. The unit must be NEBS Level III compliant, and meet all standards for UL, FCC, etc. Today's RAMs typically offer from 8 to 48 subscribers per unit in sizes varying from one rack unit to three or more.

The following picture shows a typical DLC deployment scenario using a RAM. The picture shows how the RAM unit is literally "squeezed" into any available space in the DLC cabinet.

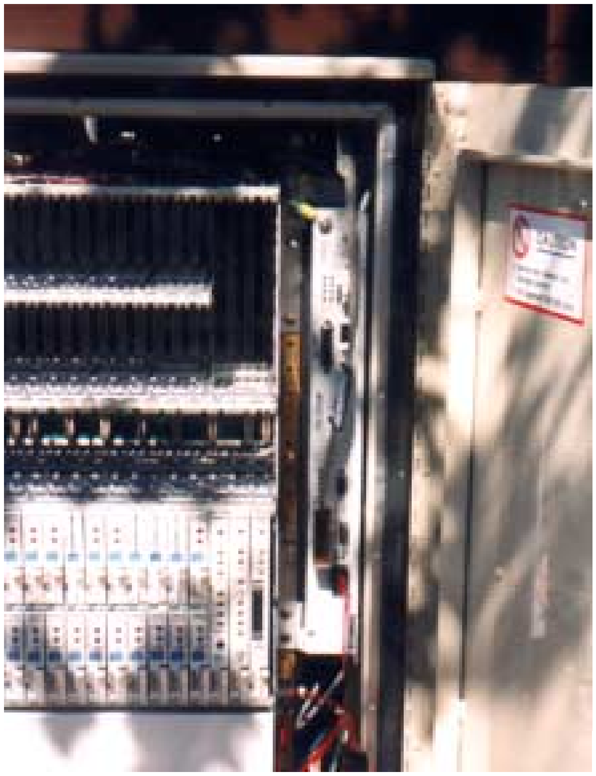


Figure 3.1 – DSL Deployment using a Remote Access Multiplexer (RAM)

The RAM products typically allow a mixture of G.DMT, G.LITE, and T1.413 ADSL service on a single platform. Some units support SDSL and VDSL. The backhaul is supported using from one to eight T1s linked with IMA, or sometimes with DS3s or higher interfaces. The device acts as an ATM bridge, bridging traffic from the customer to the ATM WAN network. It can be deployed either directly off the ATM switch, off ATM aggregation devices, or off many DSLAMs.

Many RAM products incorporate the CO-side POTS splitter inside its housing, allowing very simple tip and ring connectivity in the DLC environment. Some use special cabling for quick tip and ring connections to the protector panel.

The following diagram shows a generic deployment scenario for the RAM devices.

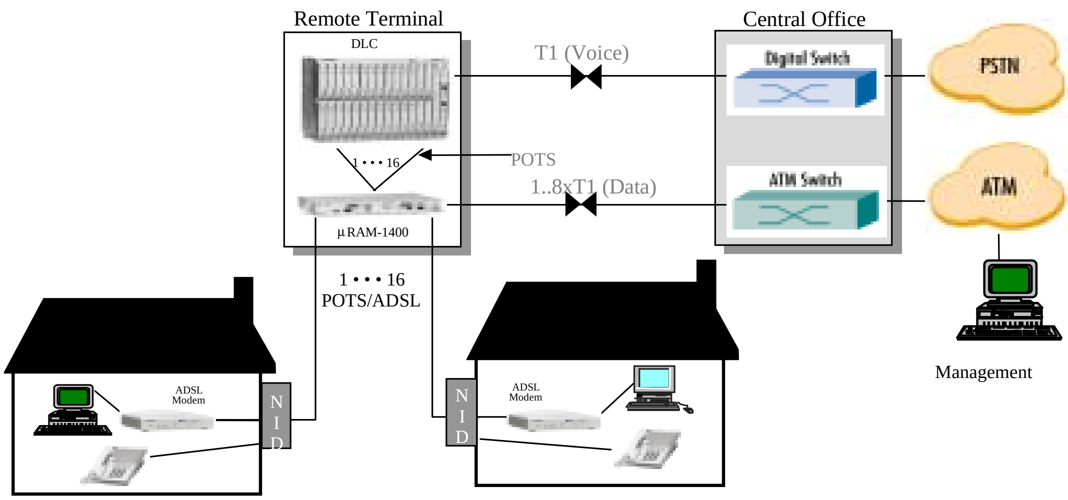


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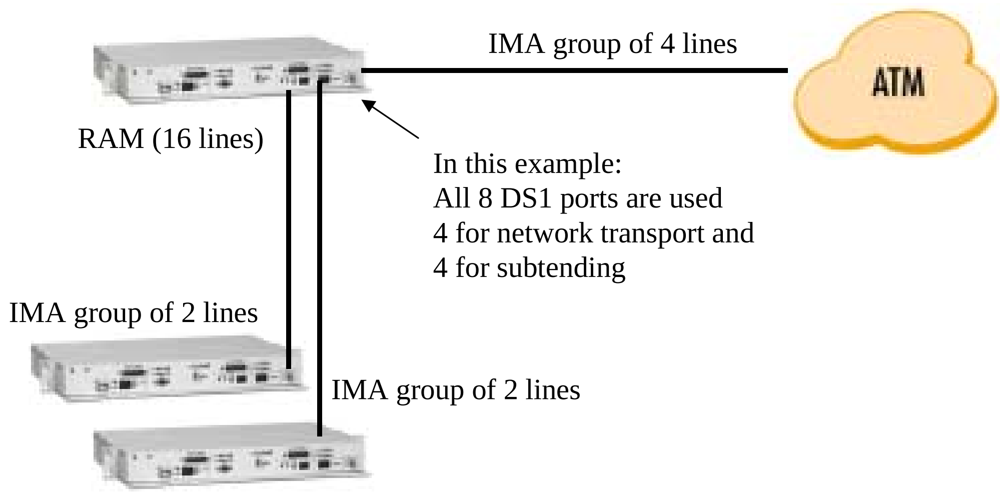
Figure 3.2 – Generic RAM Deployment Scenario

Most RAMs contain within them a fully functioning ATM switch which supports multiple QOS types, UBR, CBR, VBR, etc. In some products, the multiple T1s can be used simultaneously for backhaul and subtending, as depicted in the following diagram:



This example supports 48 subscribers in 3 Rack Units

Figure 3.3 – Subtending and Backhaul with RAMs

The RAM is uniquely capable of providing DSL service at the remote terminal without the need to deploy an adjunct cabinet or to swap out existing DLC equipment for NGDLC equipment. This limits the service providers' capital cost for providing service, and allows them to bring up DSL lines quickly and at relatively low cost. With subtending supported on many RAMs, a service provider could bring up 48 DSL lines, POTS splitters included, in three rack-units of space inside a remote terminal just utilizing "dead" space within the cabinet.

3.1.1 Description of Architecture/Technique

The Remote Access Multiplexer (RAM) was designed to be a small dense device, which provides easy access to DSL within the remote environment. RAM devices are hardened devices (industrial range temperature, NEBS Level 3, etc.) which makes them suitable for deployment in the harshest environments. Most devices range in size from 1 rack unit (1.75" high) to 3 rack units. They usually range in densities from 8-48 DSL lines, and usually include splitters. RAMs typically use DS1/E1 facilities for connection to the core network. The overall benefit of the RAM is that it allows quick, easy DSL access in virtually any environment.

3.1.2 Advantages

RAM devices allow instant DSL service turn-up in almost any environment. The small size and industrial temperature devices can be deployed equally in the CO, building basement, equipment closet, and remote terminal. Quick connect cables for power, DS1, and tip and ring pairs usually allows installation of the RAM devices within one hour or less.

3.1.3 Implementation/Deployment Issues

The RAM devices are simply a mini DSLAM, and hence have the same deployment issues as any other DSLAM. Most RAMs are typically an ADSL based device, which means that they are susceptible to interference from other services in the binder, such as T1s, HDSL, etc.

3.1.4 Operational Issues

The RAMs have been designed to be extremely easy to install and manage. Once the unit is inserted in the rack, power, alarms, DS1s, and tip & ring pairs are connected. This usually takes ten minutes or less. Once the RAM is powered up, a self test will typically operate. After the self test, the RAM will be pre-provisioned for basic ADSL service, and if the ADSL Device at the customer's site is already connected, service will commence upon training completion. The RAMs use an integrated network management system with most DSLAM vendors, so users can easily be provisioned and de-provisioned, and equipment can be managed. The units usually have very few serviceable parts, since they are self-contained devices. Typically, the only repair is to replace the fan unit, which is a modular device for easy replacement.

Spectrum management issues with the RAM are typically the same as with the DSLAM. Since RAMs often contain both T1 and ADSL lines, the T1s ideally should be in separate binders to minimize noise in the DSL binder. This is typically not a problem, since the binder back to the CO is almost always separated from the downstream customer pairs.

3.1.5 Network Management Issues

The Management Information Bases (MIBs) used by RAMs are the same MIBs used by any other DSLAM. Typically, this includes the AToM MIB, the ADSL MIB, DS1 MIBs, and a few enterprise MIBs for managing the actual device. In most cases, every RAM manufacturer has a management system, which is integrated with their own DSLAM, and some even provide an uplink interface so that the management systems can be integrated into carrier network management systems.

4.0 Integrated Access Solutions

This section addresses integrated Voice + DSL access solutions, which radically improve capital and operational costs. These integrated solutions consume less power and provide higher densities than current solutions, and they speed the installation, provisioning and deployment of DSL services. Initially, service providers have deployed DSL in the central office as an overlay, using separate DSLAMs and central office POTS splitters to combine DSL service onto the subscriber loop. However, as DSL penetration rates increase and DSL becomes a “volume” service, service providers will need to integrate Narrowband and DSL services to optimize their operations costs. Niche services are generally deployed as overlays so they don’t impact the volume POTS service operations. DSL is currently migrating from being a niche service to becoming a volume service. As a result, many equipment vendors are now offering integrated narrowband and DSL access solutions to enable service providers to lower costs, optimize operations and speed the velocity of DSL deployment. While these integrated access solutions provide significant DSL deployment benefits in the central office, the toughest issue that service providers face is implementing economically-viable solutions at the Remote Terminal (RT).

Central Office-based DSL deployment models have the benefit of space, and they typically address large serving areas of 10,000-20,000 subscribers to amortize their capital and facility investment costs. That is not the case with Remote Terminals. RT-based DSL deployment models face significant power, space, heat and economic constraints. The cost of deploying DSL at RT sites is also amortized over a very small subscriber serving area (80% of RTs serve less than 672 subscribers[10]). While the challenge of providing DSL from RTs seems daunting, the subscriber base served from RTs represents nearly 40%[11] of all subscribers in the U.S and is growing. Integrated access solutions enable service providers to address these prime DSL subscribers with quick, economically viable deployment models.

Integrated Access Solutions
This section provides descriptions of three (3) Integrated Access Solutions:

- **Digital Loop Carrier (DLC) Line Card**
  Over 28 million[12] subscribers are served from Subscriber Loop Carriers (SLCs). The AT&T SLC® Series 5 is the most popular and widely deployed DLC in the U.S. These vintage SLCs can now be upgraded to state-of-the-art broadband access vehicles with simple, low-cost integrated POTS + DSL line cards, while retaining their full POTS and legacy functions and capacity.

- **Next Generation DLC (NGDLC)**
  In the ‘90s, NGDLCs were introduced to provide greater density and dynamic time slot assignment. This enabled more efficient concentration groups and provided a generic GR303 interface to the local digital switch. NGDLCs can be equipped with a suite of interchangeable line cards that can provide a number of different services,

[10] RHK
[11] RHK 2000 Access Network System Market Forecast, February 29, 2000
[12] RHK

such as HDSL,, IDSL and ISDN, as well as DS-1 options and applications. NGDLCs can be upgraded to a Broadband NGDLC (B-NGDLC) to support ADSL with the addition of a simple, integrated POTS + DSL line card, SHDSL line card or other DSL flavors. The Broadband NGDLC RT may either be connected directly to the Residential Broadband Network or use an ATM backhaul facility to carry all data to and from the central office terminal, where the uplink to the RBN is provided. Some Broadband NGDLCs use circuit emulation to carry the voice traffic as well this transport facility and thus to eliminate the need of a separate TDM facility.

– **Broadband Loop Carrier (BLC)**
  The Broadband Loop Carrier is an emerging class of access vehicle that is 100% broadband and lifeline packet-voice capable to enable access network convergence of voice and data. The BLC is a packet-based platform (vs. TDM-based), which is optimized for profitable delivery of high volume, high churn service offerings. The BLC's unified architecture employs highly integrated, DSP-based silicon to eliminate the central-side POTS splitter, enabling delivery of voice and DSL services on every subscriber line at near POTS economics. Through remote provisioning of any subscriber line for voice and/or DSL, truck rolls and reconfiguration costs are eliminated, resulting in significant operational savings. Broadband Loop Carriers can be deployed in both central office and remote terminal applications, and because the subscriber loop is fully digitized at the access termination point, service providers can migrate TDM traffic to the converged, packet-based network on a line-by-line basis.

  This section explores in detail the implementations, advantages and applications where integrated access solutions will help service providers cost-effectively speed deployment of *DSL Anywhere*.

4.1 DLC Linecard

4.1.1 Introduction

To launch mass-market campaigns, service providers must be able to ensure DSL service availability to their entire subscriber base. While many Central Offices are now equipped to address DSL demand, Digital Loop Carrier-serving areas have been largely unaddressed.

The good news is that, as existing subscribers and new growth are being migrated from Central Offices to RTs, subscriber loops are becoming shorter, significantly increasing their DSL bandwidth capabilities.

4.1.2 The Problem

The current DSL architecture being deployed in Central Offices consists of the incumbents' POTS switch, mechanical POTS Splitters and the data affiliate's DSLAM, as well as multiple competitive carriers' DSLAMs (see figure 4.1).

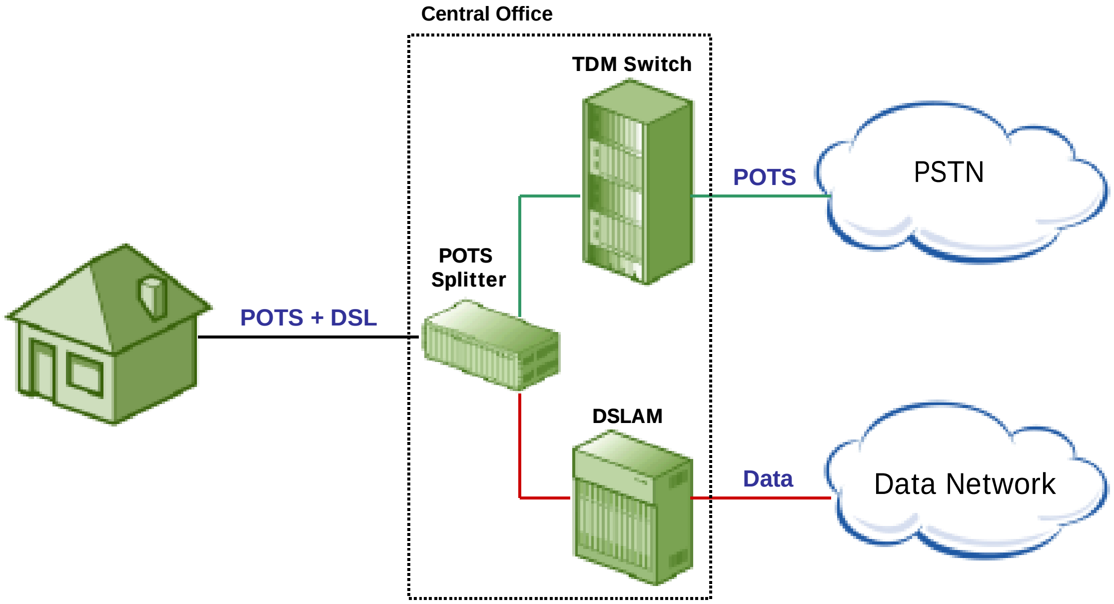


Figure 4.1 – Current DSL Deployment Model

This deployment model is difficult to extend to DLCs in the remote plant for the following reasons:

Space Constraints
Central Offices have the luxury of having collocation space available for DSLAMs for the data affiliate and multiple competitive carriers. DLCs are located at the edge of neighborhoods in small, outside-plant cabinets, CEVs (Controlled Environmental Vaults), huts or mounted on poles. In the majority of cases, space is not available to place overlay DSL equipment.

Right-of-way issues, esthetics and high costs deter service providers from building cabinet farms at the edge of neighborhoods to house overlay DSLAMs and POTS Splitters. To further complicate matters, the SAI (Subscriber Access Interface) is not always collocated with the DLC equipment. As a result, carriers are forced to implement non-standard wiring methods to gain access to subscriber loops.

Capital Costs
Implementing overlay DSL deployment architectures for DLCs can result in high start-up costs. Most overlay remote DSL solutions require new cabinets, pouring pads, incremental commercial power, etc. These significant start-up costs require a significant DSL penetration level for service providers to justify DSL deployment in many remote locations.

Smaller Serving Areas
While DSLAMs in Central Offices have access to thousands and tens of thousands of subscribers, DLC serving areas are smaller. Seventy-five percent (75%)[13] of all DLCs deployed address 700 lines or less with many DLC sites addressing fewer than 200

[13] RHK 2000 Access Network System Market Forecast, February 29, 2000

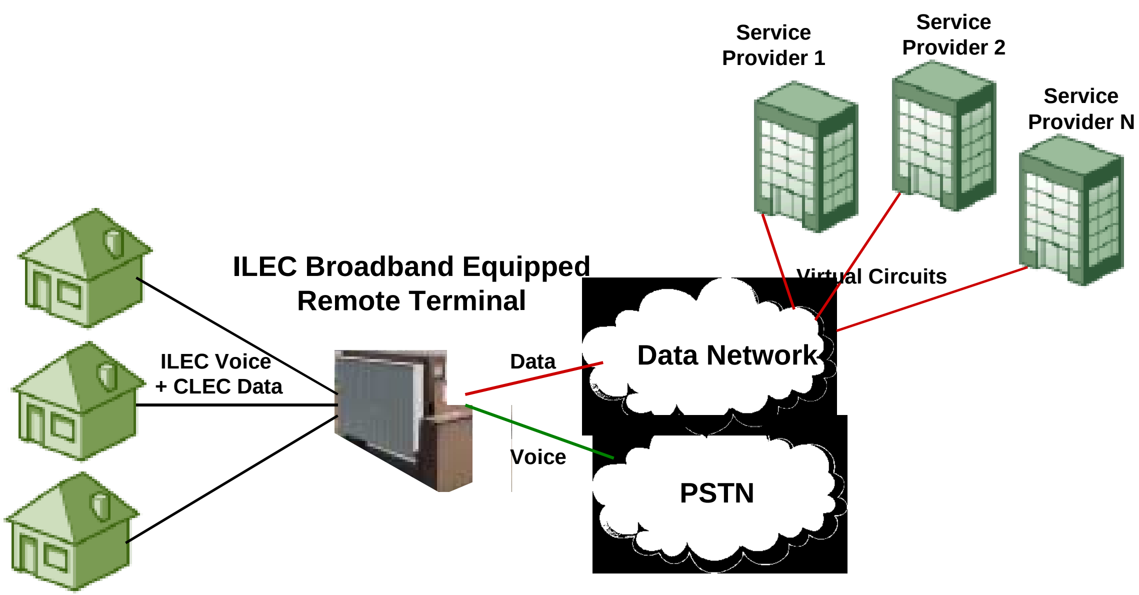
subscribers. These small serving areas make it difficult for ILECs and CLECs to justify the high initial investment required to put overlay DSL infrastructure in place to compete for such a limited number of subscribers.

Speed of Deployment
Overlay DSL solutions at remote sites typically result in complex installations; pouring pads and installing remote cabinets for POTS Splitters and remote DSLAM equipment, etc. These installations are time consuming and resource intensive, making it difficult for service providers to quickly respond to DSL demand.

4.1.3 The Solution: Integrated POTS + DSL linecards

To significantly increase the DSL service coverage, to address the significant and growing installed base of subscribers served from RTs, service providers must implement a DSL deployment model that is simple, elegant, easy to deploy and cost effective. One such solution is the implementation of integrated POTS + DSL linecards.

Integrated POTS + DSL linecards enable service providers to quickly and easily upgrade the large installed base of DLCs for DSL service. In addition, new and emerging DLCs can be deployed pre-equipped with integrated POTS + DSL linecards. The architecture depicted in Figure 4.2 illustrates the simple solution that integrated POTS + DSL linecards enable.



Service providers share common facilities: speeds deployment and minimizes costs.

Figure 4.2 – DSL Deployment Model for Digital Linecards

The integrated POTS + DSL linecard fits into the existing DLC linecard slot. DSL gains access to the POTS loop appearance, thus eliminating any complex and time-consuming wiring to the protection block, SAIs, POTS Splitters, etc. In addition, the integrated POTS + DSL linecard eliminates the need for incremental equipment, incremental cabinets, larger cabinets, pouring new pads and all the issues related to overlay solutions.

The POTS service remains intact and the voice traffic continues to be backhauled to the Central Office over the existing POTS transport infrastructure. There are no changes or impact to the existing ILEC voice operations, maintenance or procedures.

The DSL traffic is directed to a new, common ATM network interface card, placed in an available slot with backplane access to each linecard. The DSL traffic is aggregated on the ATM card and interfaces to the carrier's transport system via T1s, DS-3 or OC-3. The DSL traffic is backhauled to an Optical Concentration Device (OCD)[14] at the Central Office. The DSL traffic is unbundled at the OCD and available to the ILEC and competitive carriers via permanent virtual circuits (PVCs).

4.1.4 Advantages of integrated POTS + DSL linecards

This integrated POTS + DSL linecard deployment architecture makes it possible for the millions of residential subscribers currently served from SLC® Series 5 DLCs to become among the first customers to receive broadband DSL services, rather than being constrained to be among the last. Integrated POTS + DSL linecards enable the following DSL coverage benefits:

- **DSL Coverage -** DLC serving areas account for a significant portion of the target DSL subscriber base. This implementation enables service providers to launch mass-market service campaigns.
- **Simple -** Integrated POTS + DSL linecards eliminate the need for overlay cabinets, complex wiring, pouring pad and resource-intensive installations.
- **Low Start-up Cost -** DLCs can be equipped for DSL service on a linecard-by-linecard basis. This level of granularity, and eliminating the need for incremental or enlarged cabinets, keeps start-up costs at minimum.
- **Scalable -** The continued advancements in DSL silicon technology allow service providers to upgrade legacy DLCs, on a granular, linecard-by-linecard basis to address required and projected DSL penetration levels — with no reduction of POTS port capacity.
- **Speeds Deployment -** Simple linecard upgrades can be deployed rapidly versus overlay solutions.
- **Amortized Backhaul -** All the DSL traffic is backhauled to the OCD for service unbundling. The DSL backhaul facilities are amortized over all the DSL subscribers

[14] The OCD is an ATM switch. More information on OCD unbundling is available at the FCC under CC Docket N. 98-141-Ownership of Plugs/Cards and OCDs.

in the serving area. As a result, service providers achieve the most cost-effective and efficient architecture to provide DSL service to this subscriber base.

- **Reliability -** The integrated POTS + DSL linecard deployment model eliminates complex wiring, eliminates the need for overlay equipment and significantly reduces the number of failure points in the network.

- **Economically Viable -** An integrated POTS + DSL linecard deployment architecture for DLCs is a cost effective, expedient method for service providers to achieve mass-market DSL deployment in remote serving areas. Viable economics enable service providers to offer affordable DSL services to this significant segment of the subscriber base. The integrated POTS + DSL linecard deployment architecture significantly lowers the barrier to entry for competitive service providers, resulting in a more competitive environment for DSL service offerings.

- **Regulatory -**. On Sept. 7, 2000, the FCC granted a modification of certain conditions in SBC's merger agreement with Ameritech, which created a separate data affiliate to provide advanced services. The amendment allowed SBC's ILECs to own and deploy integrated POTS + DSL linecards[15] in Remote Terminals, along with associated transport and OCDs, as part of its Project Pronto initiative. The FCC reasoned that "[w]e expect consumers will benefit not only from a more rapid deployment of advanced services [DSL], but from the increased choices that stem from the competitive safeguards contained in the SBC proposal."[16]

  This demonstrates that the FCC believes that the integrated POTS + DSL linecards architecture for Digital Loop Carriers will speed DSL deployment and promote competition, and that speeding DSL deployment to under served areas is a critical agency goal.[17] In summary, integrated POTS + DSL linecard architectures are consistent with the FCC's goals and the current and emerging regulatory environment.

4.1.5 Conclusion

In support of DSL Forum's interest in expanding service providers' ability to deploy "DSL Anywhere," the integrated POTS + DSL linecard deployment architecture is a quick, simple, and cost-effective approach to provide DSL service to many of the more than 68 million subscribers served from DLCs. While this technology is ideally suited to enable DSL deployment from the most widely deployed first generation DLCs, the integration of POTS and DSL on linecards will also enable a new generation of broadband-capable RTs, helping service providers continue to drive fiber closer to subscribers.

[15] SBC used the term ADLU to describe the POTS + DSL linecards (ADSL Distribution Line Unit) they plan to deploy in their DLCs.
[16] FCC CC Docket No. 98-141 ASD file No. 99-49 September 9, 2000 page 7 sections 10.
[17] The agency also has a statutory mandate to speed advanced services deployment in Section 706 of the Telecommunications Act of 1996.

4.2 Next Generation Digital Loop Carriers

4.2.1 Introduction

NGDLC (Next Generation Digital Loop Carriers) have been deployed since the 80's as an access platform that provides residential and business voice and data services. NGDLCs provided the carriers with multiple features, primarily for the deployment of narrow-band services based on DS0s:

1. With NGDLCs, each Central Office can serve end-users far beyond the local customer serving area (12,000-18,000ft). Fiber or T1 span lines can be deployed deeper into the access network--to multiple CSAs. In each one NGDLC remote serves multiple residences and businesses.
2. Relying on open standards between the NGDLC and the Central Office (Sonet, GR-303, TR-008, T1 span lines), carriers can better select the vendors based on price/performance with assured integration into the network.
3. Class 5 switches can be better utilized by equipping high-capacity digital links (i.e. TR-008 and GR-303) instead of analog voice lines. Additionally, one local switch can serve extended geographical areas, which overlap with the increase capacity evolution of Class 5 switches (100,000+ subscribers).
4. Fiber transmission is superior compared with large number of copper loops deployed all the way to the central office (the feeder plant portion of the access). Fiber as a feeder plant reduces lifetime costs and paves the way to broadband deployment.

By now, 50% of all new voice lines are deployed from NGDLC remotes. They are deployed in many applications: outside plant, co-locations, in-building etc. The versatility of NGDLC manifested by the support of different drop side services over several transport facilities, made them flexible enough to fit into residential, small/medium business in different service provider arrangements (ILECs, CLECs, etc).

It is clear that DSL is an emerging service for both residential and business customers. As NGDLC are supporting over 35% of all North American access lines, DSL service needs to be provided from the NGDLC remote location. The carrier is faced with several options of equipping the NGDLC with DSL, but primarily it will be either:

1. Deploying an overlay remote DSLAM or mini-RAM at the NGDLC location
2. Upgrading the NGDLC to support DSL
3. Replacement of the NGDLC to support DSL and voice

This section will provide insight for the second option--making the upgrade for NGDLC. A B-NGDLC is defined as an NGDLC upgraded to support broadband DSL based services. The following text discusses the guidelines to assure that the B-NGDLC has a similar flexibility of a CO based DSLAM, while maintaining the capacity and quality of its narrowband services.

4.2.2 Broadband NGDLC requirements

NGDLC were originally designed to provide narrowband services. The need for integrated DSL in NGDLC, brought along with it, the essential requirement of cell based fabric. To provide a good integrated solution the B-NGDLC should meet the following set of requirements:

Efficient Transport - DSL will require cell transport that will be carried with the TDM traffic. The transport facilities to the NGDLC should be flexible and cost effective for carrying both services.

Sufficient DSL Density - The B-NGDLC is expected to provide sufficient density of DSL services to address the envisioned DSL take rates. The capability to integrate splitters on the B-NGDLC line card is also important as it eliminates the space required for a separate splitter shelf. POTS density should not be compromised as a result of DSL support.

Market Segments - NGDLCs are supporting residential and business services. DSL upgrades in NGDLCs should be addressing similar segments, with their respective needs.

Loop Management - Copper loop management, which includes wiring, qualification, and access to metallic test access bus, are important for life time management of the DSL assets in NGDLCs.

Network Architecture - B-NGDLCs should support the same set of network topologies and universal / integrated operation modes as existing NGDLC.

Management and Operations - Management and Operations should accommodate the deployment of DSL and voice from the same NGDLC box. The B-NGDLC EMS and NMS should be capable of managing both services simultaneously

By reviewing the aforementioned requirements, and fulfilling the guidelines that emerged out from them, a carrier can extend the DSL service to NGDLC locations while maintaining network planning practices and meeting business goals.

4.2.3 Broadband NGDLC Architecture

Cell Transport

Provisioning DSL service at the NGDLC remote will require a cell-based transport to the CO. As the DSL is integrated with narrowband services, the transport needs to accommodate TDM and cell based traffic. There several options of designing that, each with different merits and is tailored to specific application.

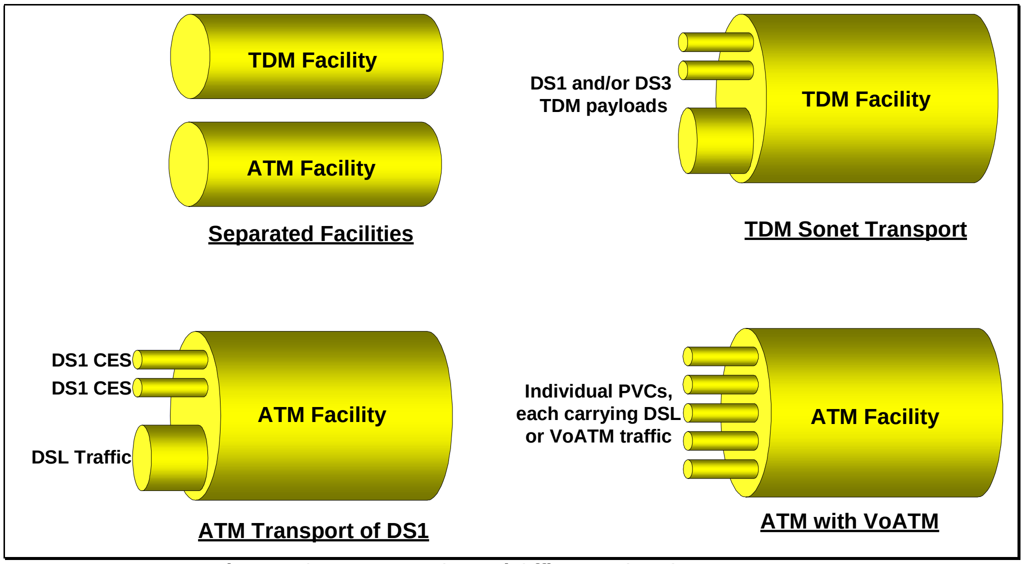


Figure 4.3 Remote to Central Office B-NGDLC Transport

In certain applications a service provider may choose to physically separate the DSL back-haul traffic from the TDM traffic at the remote. In such configurations, the TDM traffic and the ATM traffic are separated into two different physical back-haul facilities; each can be based on copper (HDSL, T1) or fiber. The CO based equipment is similarly separated into TDM and ATM functions.

In other applications and deployment models, service providers may benefit from using the same back-haul facility to carry both data and voice traffic. This eliminates the need to deploy new fiber or copper between the RT and the CO to carry the DSL traffic.

There are two main options for this converged transport:

Carry TDM and Data over ATM:
The TDM traffic can be transported either by:

- Performing Circuit Emulation for individual DS1s, or
- The individual DS0s are encapsulated in AAL1 or AAL2 (i.e. BLES), thus integrated into the cell payload.
  The chosen architecture will depend on the mix of TDM and ATM traffic, the underlying hardware and the Class 5 network planning.

Carry TDM and Data over TDM:
A single TDM facility may carry a mix of data and voice. For example, well-standardized TDM Sonet can occupy one of the DS3 or several DS1 (in an IMA group) containers to transport the ATM payload of the DSL ports. Carrying both services over TDM may have a significant advantage at the first stage of DSL penetration, as it allows the service provider to merely deploy the DSL linecards and reuse the existing facilities to carry the data.

It seems logical that as convergence becomes a more definite requirement, an ATM payload for voice and DSL will be more desirable. Whenever there is still incremental need for DSL, or there are some equipment limitations, the separation of the ATM and TDM transport is an advantage.

4.2.4 NGDLC Remotes Foot Print

Remote Terminal line card density and overall shelf density are usually important features as they translate to real estate sizing. Integrated DSL within the remote is usually implemented as DSL line card with multiple interfaces. Compared with in-door application, heat dissipation specification in temperature hardened environment is more tight, which may lead to DSL densities which are lower in B-NGDLC compared with CO based DSLAMs. When sizing such a remote, a consideration needs to be taken as to overall shelf capacity for DSL, voice and some mixture in-between. Some line cards are being offered with integrated ADSL, splitter and voice channel, which mitigate copper loop management and the requirement for separated splitter shelf. However, other DSL flavors (as G.shdsl) needs to be contained within a card without the voice support.

Other equipment requirements in the remote need to be planned ahead of the integrated DSL deployment. Power system, battery backup, surge protectors and alike are common components in the remote, which need to be engineered accordingly in the presence of DSL.

4.2.5 Spectrum of Services

NGDLC is providing service to residences and small business customers. In residences loop start voice lines are dominating. In the small business segment, in addition to the loop start, there are ISDN, analog PABX, 56kbps data lines (DDS), ground start voice lines, FXS and others. It is expected that a B-NGDLC will have similar DSL spectrum of services. While ADSL is the dominant service to the residence (the equivalent to loop start voice), symmetrical DSL (SDSL and G.shdsl) are favored in the business segment. The B-NGDLC is required to support these DSL versions. Usually implementing different DSL line cards will allow the service provider to support both.

4.2.6 Copper Loop Management

Copper loop management provides carriers with tools to analyze copper pairs for DSL service, designate the wiring and the physical connection, and then to provide life cycle management. Usually a specialized test head (equipped to test DSL spectrum) will gain "tip and ring" access to each served copper loop and perform the maintenance. In CO based deployment, a loop qualification system is cost justifiable across all the DSLAM assets in the CO. In a remote, where DSL port count is significantly lower, a more cost-effective solution is desirable. The need for loop testing in B-NGDLC remotes is augmented by the fact that these locations are numerous and not nearly accessible as the CO.

One of the testing system components in the remote is the integrated metallic test bus built in the NGDLC. Most NGDLCs support metallic test access, which is a natural extension to provide metallic test access to the DSL line cards. The testing features will require supporting all the DSL variants in the NGDLC. The location of the splitter may be a challenge to loop qualification.

4.2.7 Network Architecture

NGDLCs are usually composed from RT (Remote Terminal), deployed at the pedestal and a COT (Central Office Terminal), deployed in the CO. The COT provides the fiber or copper transport to the RTs and interconnects with the Class 5 switch. Relying on TR-57 interface (analog voice) to the Class 5 mandate that a COT will be deployed. NGDLC remote in an integrated mode (TR-008 and GR-303) may require a COT for doing only a transport function or a COT-less application is deployed (with external transport functions). DSL based equipment is architecturally equivalent to NGDLC remote, in a way that there is no DSL equipment equivalent to a "COT". Another model is that the COT has a function of an ATM edge switch for DSL services. Therefore, integrated DSL in remotes will either utilize the B-NGDLC COT, which was upgraded to ATM switching capabilities, or the NGDLC COT function will be eliminated and replaced by ATM edge switch.

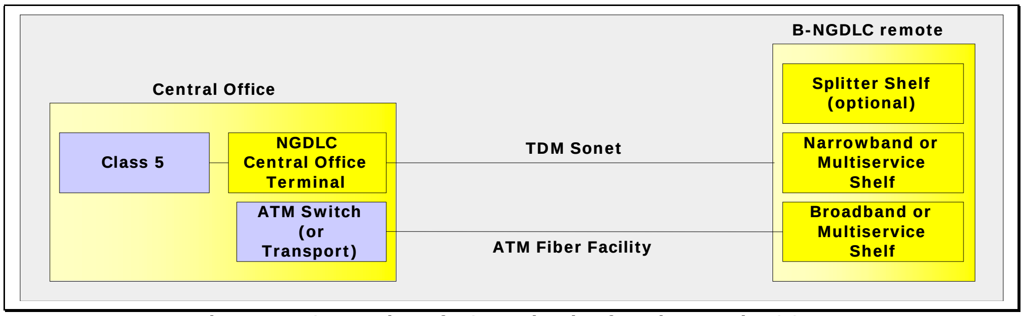


Figure 4.4 Separation of DSL and Voice functions at the CO

In figure 4.4 the first option is shown, in which TDM traffic is separated from the broadband traffic, at the remote. The NGDLC COT maintains its functions, while DSL data traffic is routed to the ATM switch. There is a physical integration of DSL line cards in the remote, however the transport and the CO based equipment handle the DSL and TDM traffic separately. This configuration may be desirable in certain scenarios, especially in which full scale voice and DSL convergence is not desirable (separating DSL and voice assets in the CO) or not possible (older versions of NGDLC). The other case in favor of this option will be that the remote is already fully configured and carrying voice traffic and an upgrade to the converged transport is technically not possible.

In figure 4.5 a second option is shown, in which the NGDLC COT is upgraded to function both in the ATM domain and in the TDM domain. The DSL and voice traffic is consolidated to the same transport facility, and then it is terminated in the COT. At the Central Office, the ATM traffic is aggregated toward the ATM core network while the TDM traffic is switched to the Class 5. This solution is desirable especially in the case where the remotes generate relatively small ATM traffic capacity. In that case the COT aggregates multiple remote terminals' traffic over a single ATM interface to the RBN. Additionally, in this architecture, the COT can function as an Optical Concentration Device (OCD), unbundling the DSL traffic and flexibly routing it to the data affiliate and competitive carriers.

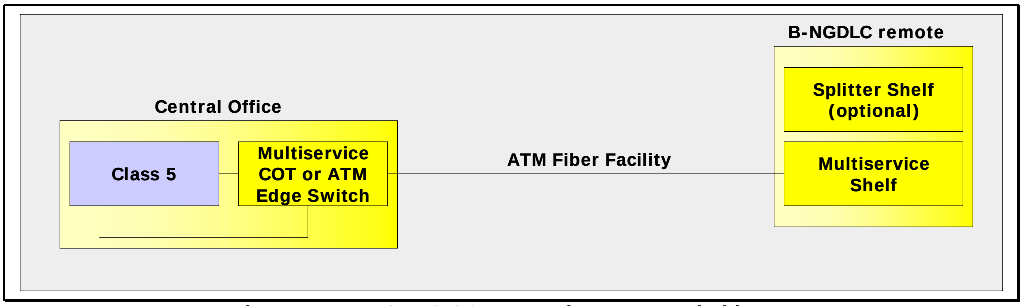


Figure 4.5 B-NGDLC COT upgrade to ATM switching

Where there is a major broadband demand at the remote, and cell traffic will dominate the transport, it is assumed that B-NGDLC remote functions will be optimized to cell traffic. The voice traffic will be carried in the ATM facility either in native mode (i.e. DS1s) or as VoATM. This application is shown in figure 4.6. In this case the NGDLC is dominated by broadband traffic, and it is assumed that the CO based equipment will be an extension of the broadband core network (i.e. ATM edge switch). Such configuration may be suited better to next generation voice switching, but can be complex for legacy provisioning of voice service (TDM GR-303, TR-008).

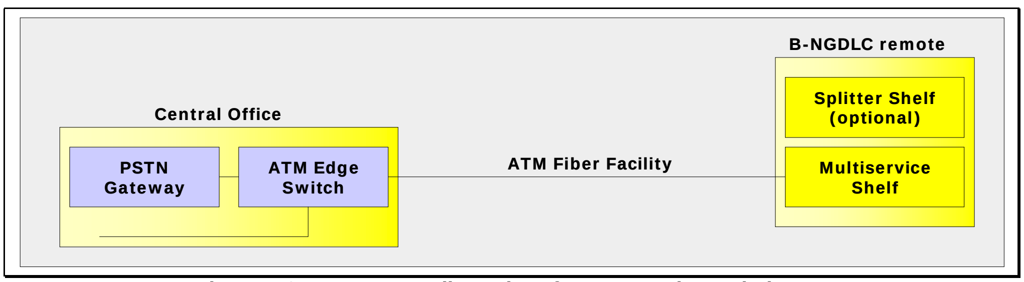


Figure 4.6 Remotes as direct drop from ATM edge switches

4.2.8 Advantages of Broadband NGDLC

An upgrade of NGDLC to a B-NGDLC has the following benefits:

- **Minimal start-up cost -** The first step requires the carrier to only replace those line cards that require DSL, and may not even involve deploying new transport facilities.

- **Simplicity –** The solution is simple and does not require the carrier to change the equipment, network architecture and operation.

- **Versatility:** The solution maintains all existing flavors of narrowband services while also allowing multiple DSL flavors to address different market segments. A single remote terminal can mix and match any of these narrowband and DSL based services.

- **Scalability -** The solution can scale to significant DSL take rates that may serve for a long term DSL deployment. Upgrade to broader back-haul facilities is possible, but required only when the data bandwidth justifies it, on a remote terminal basis.

- **Efficient ATM network interface –** The solution may leverage NGDLC network topologies, (e.g. star), to aggregate many subscribers' data onto a single ATM network interface, or multiple interfaces for unbundling purposes.

- **Consolidated Management –** The solution allows the carrier to continue using the same Element and Network management platforms for both the narrowband and broadband services.

4.3 Broadband Loop Carrier

4.3.1 Introduction

The purpose of this section is to introduce an emerging class of access vehicle, the Broadband Loop Carrier (BLC), which will dramatically improve availability of DSL service.

4.3.2 A Solution: Broadband Loop Carrier (BLC)

A new generation of access vehicle, the Broadband Loop Carrier, is designed to cost-effectively deploy "DSL Anywhere." The BLC is optimized to address full DSL demand. It cost-effectively addresses the growing subscriber base served from Remote Terminals, and enables a seamless migration from today's TDM network to a converged, packet-based network. The key attributes of a BLC are as follows:

(a) POTS + DSL on every line

A fundamental characteristic of the BLC is the integration of POTS and DSL on every line. POTS has long been the model for the delivery of ubiquitous and affordable volume service. The integration of POTS and DSL into a single access termination point drives the cost down to approach that of a POTS-only solution. The BLC architecture requires a fundamental re-thinking of core silicon and linecard technology, but this level of integration enables the BLC to offer several key attributes necessary to support affordable mass-market deployment:

- **Reduced capital costs -** DSL is available on every line, at prices approaching POTS only, and with no sacrifice to POTS densities. Every subscriber line supports lifeline telephone service and is "DSL ready" the moment it is installed, which means that service providers can scale service rapidly, without additional capital or sparing costs, as their DSL demand grows. In addition, there is no requirement to trade off voice ports for DSL ports, or to change or add cards when the service mix changes.

- **No Truck Rolls -** Because POTS and DSL are available on every line, and integrated loop testing and qualification capabilities are provided for every line, all operations, provisioning and maintenance can be performed remotely. All DSL service requests are handled through completely hands-off remote provisioning from the network operations center. That means no truck rolls are required. No one has to touch the box to turn up or turn down POTS and/or DSL service, allowing service providers to realize the lowest possible service activation, and lifecycle costs.

- **Network simplicity and reliability -** The BLC's integration of POTS and DSL helps eliminate the need for separate overlay access networks. A single network significantly reduces complexity and points of failure, resulting in greater network reliability. Because DSL is available on every line, re-wiring, and wire tromboning[18] to POTS Splitters and DSLAMs is eliminated. POTS and/or DSL service can be provisioned, tested, monitored and maintained remotely. Line and station transfers can be virtually eliminated.

(b) Full Spectrum Connectivity — No POTS Splitters

- The integration of POTS and DSL eliminates the need for Central Office POTS Splitters. No POTS splitters are needed – either externally or on the line card itself. As a result, service providers have full spectrum connectivity to the subscriber loop. This means that test facilities have access to the full loop for testing and loop qualification, without requiring awkward or complex test connections and POTS Splitter work-arounds. In addition, bandwidth is not stranded by low-pass or high-pass filters, paving the way for new service capabilities, such as implementation of the All Digital Loop (ADL).

- **Regulatory Issues — Competitive Access -** Recent regulatory developments support the conclusion that an integrated POTS + DSL architecture for Remote Terminals will speed DSL deployment and promote competition. On Sept. 7, 2000, the FCC granted SBC's request to allow its ILECs to own and deploy integrated POTS + DSL equipment in Remote Terminals, along with associated transport and OCDs. "…We [the FCC] expect consumers will benefit not only from a more rapid deployment of advanced services [DSL], but from the increased choices that stem from the competitive safeguards contained in the SBC proposal."[19] In summary, the FCC believes that the integrated POTS + DSL architecture for Remote Terminals will speed DSL deployment and promote competition.

The environmentally hardened BLC provides the most cost effective and efficient architecture for enabling competitive access to DSL subscribers served by RTs. Integrated POTS + DSL linecards eliminate any complex and time-consuming wiring to protection blocks, SAIs, and POTS Splitters. These linecards also eliminate the need for incremental cabinets and equipment, pouring of new concrete pads and all the issues related to physically co-located overlay solutions. Figure 4.8 illustrates the BLC Remote Terminal architecture for competitive access.

[18] Tromboning is a term, which describes the incremental MDF (Main Distribution Frame) appearances and complex wiring and routing from the POTS switch to the MDF to the DSLAM POTS Splitters, back to the MDF, then to the subscriber.

[19] FCC CC Docket No. 98-141 ASD file No. 99-49 September 9, 2000 page 7 sections 10.

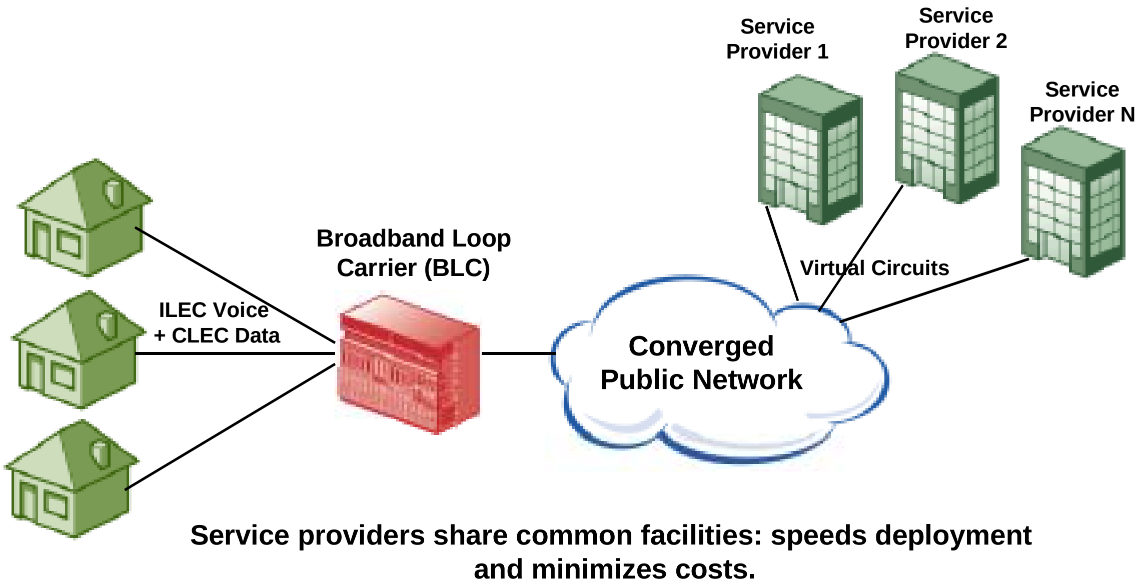


Figure 4.8 – DSL Deployment Model for Broadband Loop Carriers

The POTS (TDM) traffic can be backhauled to the Central Office via TR08 orGR303, or packetized and carried with the data traffic to an OCD. The DSL traffic is backhauled to the OCD at the Central Office. The DSL traffic is unbundled at the OCD and available to the data affiliate and competitive carriers via virtual circuits (VCs).

c) Seamless Transition to the Converged, Packet-based Network

The BLC enables a seamless transition from today's TDM network to a converged, packet-based network by supporting optional voice packetization at the line termination point. Service providers can packetize voice traffic, on a per line basis, at the access termination point in the line card, and then carry both voice and data traffic to the converged packet network. Expensive TDM voice grooming is eliminated, providing significant savings by eliminating costly GR-303 switch-based interfaces. In addition, there is no forced trade off of packet voice ports for DSL ports, and no requirement to change or add cards as the service mix changes.

With this architecture the transition of voice to packet is completely transparent to the subscriber so lifeline service remains intact and no IAD, special "packet/IP" CPE, or change in the subscriber's telephone set is required. At the same time, the BLC architecture remains fully compatible with VoDSL products that carry multiple derived voice channels in the DSL band and use IADs at the subscriber/business premise.

The BLC provides tremendous flexibility in allowing line-by-line migrations to the emerging packet/softswitch network. Whereas most other platforms must cut-over in wholesale fashion from TDM to packet, the BLC provides the option to offer differentiated tariffs for VoP services on a discrete line-by-line basis. As the BLC accommodates both MGCP and Megaco/H.248 based call control, only software activation is required to begin operation with a voice over packet infrastructure.

4.3.3 Conclusion

Integrated POTS + DSL Broadband Loop Carrier offers a simple and cost-effective architecture. This architecture enables DSL to become a mass-market service by making DSL as ubiquitous and affordable as POTS. The integration of POTS and DSL on linecards enables a new class of Broadband Loop Carriers, which help service providers continue to drive fiber closer to subscribers and deliver “DSL Anywhere.” Equally important, the BLC provides service providers seeking to deploy DSL Anywhere today, with the investment protection they require to implement a graceful migration to the converged packet-based network using the same equipment infrastructure.

5.0 Loop Extenders and Repeaters

When deploying DSL Anywhere, the major limitation in delivery of the DSL service is the deployment range of the selected DSL technology. Each DSL technology is limited by two major constraints: the noise environment of the copper facility and the reach of the DSL technology used to deliver the DSL service. The noise environment of the copper facility is affected by crosstalk from services co-located in the same binder group as well as noise generated by external sources such as power lines and radio transmissions. The reach limitation of a DSL technology is directly related to the line code used by the DSL technology.

This section discusses the techniques available to resolve deployment limitations of the copper facility. Two mainstream techniques are loop extension technologies and repeaters.

- **Loop Extension**

  Loop extension technologies are used to improve the ability to deploy a given service. Depending upon the given noise environment, the performance of differing DSL technologies will vary greatly. In these cases, using a different loop technology to transport the DSL service will be the difference in reaching a customer or denying service to a customer.

- **Repeaters**

  The term repeaters generically refer to both regenerators (those devices the recover and regenerate a signal) and amplifiers (those devices that amplify the signal level). Repeaters are deployed in the outside plant to extend the deployable range of DSL technologies. A single repeater can increase the deployable range of a DSL technology up to twice that of a non-repeater deployment.

5.1 Loop Extension

Loop extension is one of the most popular applications of DSL technologies. Loop extension technology is the application of DSL technologies to improve the ability to deploy a given service.

HDSL and HDSL2 are good examples of loop extension technologies. For years T1 service was deployed using an alternate mark inversion (AMI) type signal requiring significant loop engineering to remove bridged taps and to design in repeaters. With the advent of HDSL (and more recently HDSL2) T1 services can be deployed on copper pairs with bridged taps and without repeaters when deployed over the Carrier Serving Area (CSA) ranges (basically 12kft spans).

Loop extension technologies are available today for the delivery of T1, ISDN and DDS. These loop extension technologies provide service providers the ability to deliver services more cost efficiently than with standard delivery techniques.

5.1.1 Description of Architecture/Technique

Loop extension technologies are not designed to replace services deployed in the network, but are designed to improve the ability to deploy services in the network. An easy way to explain this application of DSL technology is the application of HDSL2 (ANSI T1.418) to the delivery of T1 services at 1.544Mbps.

The old standard delivery method for T1 was using an AMI signal over 2-pairs. One pair was used for the transmit path; the other pair was the receive path. Due to crosstalk problems, the two pairs had to be deployed in separate binder groups. Each pair had to be engineered to remove all load coils and bridged taps. On a typical CSA loop (12kft of 24AWG cable) T1 had to use 2 repeaters to complete the circuit. Figure 5.1 shows the typical deployment of a T1 service using the original AMI type signals.

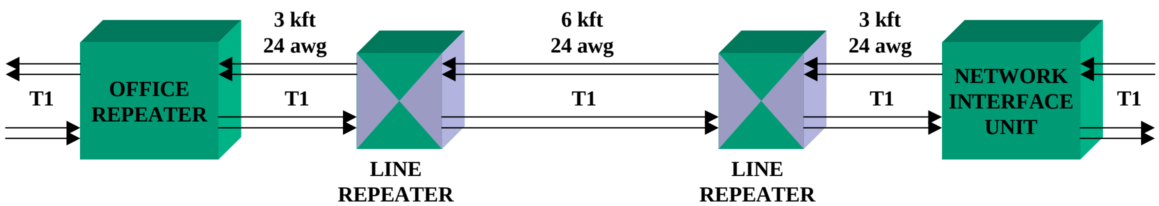


Figure 5.1 - T1 Service with AMI Deployment

The deployment of T1 services was costly and time consuming using the original AMI technology. In contrast, HDSL2 has applied advancements in technology to the deployment of T1 services to improve the service providers' ability to deliver T1 services. HDSL2 uses Trellis Coded Pulse Amplitude Modulation (TC PAM) with spectral shaping to provide T1 service on a single pair of copper. HDSL2 can be deployed at CSA ranges without using repeaters and can tolerate up to 2,500 feet of bridged taps. Figure 5.2 shows the typical deployment of T1 services using HDSL2.

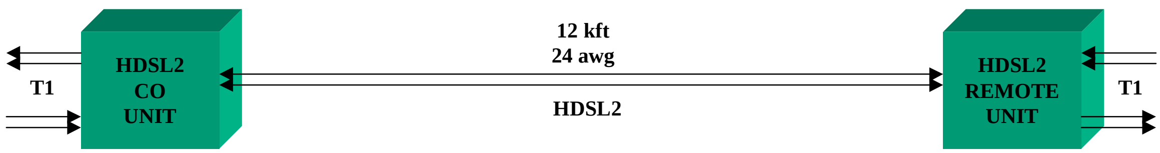


Figure 5.2 - T1 Service with HDSL2 Deployment

In this application, HDSL2 provides a transport for T1 services: T1 in – T1 out. In general that is what any loop extension technology does: provides a better transport for a given service.

5.1.2 Advantages

Each different loop extension technology provides its own set of advantages depending on the application. However, the general purpose of loop extension is to provide the following advantages:

Improved Performance. Loop extension technologies typically incorporate more advanced algorithms that allow increased performance over differing types of interference and impairments on the circuit.

Increased Range. Loop extension will typically either eliminate or decrease the need for line repeaters. This reduces the deployment and maintenance problems involved in deploying repeatered services to customers.

Ease of Use. The overall goal is to make the service easier to deploy. By improving performance, reducing engineering requirements and reducing the need for repeaters, loop extension technologies make it easier to deploy services.

5.1.3 Implementation/Deployment Issues

Loop extension technologies are widely deployed domestically and internationally. The delivery of ISDN, DDS, T1 and E1 are typically deployed by some means of loop extension. Unfortunately most loop extension technologies are proprietary to a specific vendor. Proprietary technologies require that service providers coordinate both central office and remote units to ensure proper operation of the technologies. Only with the advent of standards based loop extension technologies such as HDSL2 will ubiquitous deployment of loop extension technologies take place.

5.1.4 Operational Issues

Loop extension technologies pose significant maintenance and troubleshooting problems. As previously mentioned, most loop extension technologies are proprietary. Because they are proprietary, there usually are not test sets available to provide physical layer testing of the loop extension technology. If equipment is available, it too can be proprietary and costly. Only as the loop extension technologies are proliferated or are standardized throughout the industry does the availability of maintenance and test equipment become readily available.

In addition to maintenance and troubleshooting issues, provisioning issues arise with new technologies. When loop extension technologies are first provisioned it is typically a manual process for the service provider. The deployment of loop extension technologies typically starts out as the exception not the rule. In this case it is simple to keep up with the manual engineering of these services. As the loop extension technology matures and becomes more cost effective, it becomes the rule as opposed to being the exception. In this case the service providers operational systems must be adjusted to provide automated, flow through provisioning of the loop extension technology. While this is not a complicated process, it does require planning commitment from the service provider to make it successful.

5.2 Mid-Span Repeater

5.2.1 Description of Architecture/Technique

Repeaters may be implemented to extend the deployable range of a DSL service. Typically a repeater will have the ability to double the deployable range of a DSL technology. Repeaters are active elements installed in the outside loop plant, and are either amplifiers or regenerators. Amplifiers amplify and equalize the signal, while regenerators recover and regenerate the signal.

Regenerators have been deployed in all major digital local loop technologies to date (including DDS, ISDN, T1, and HDSL) except ADSL. DDS, ISDN, T1 and HDSL repeaters operate as regenerators. ADSL repeaters operate as amplifiers. The basic deployment of repeaters varies slightly depending on the technology being deployed. The general rules of deployment are that the repeaters are span-powered and the deployment guidelines between any two network elements (CO to Remote, CO to Repeater, Repeater to Remote, and Repeater to Repeater) are the same.

Below is a simplified block diagram of a typical repeater deployment.

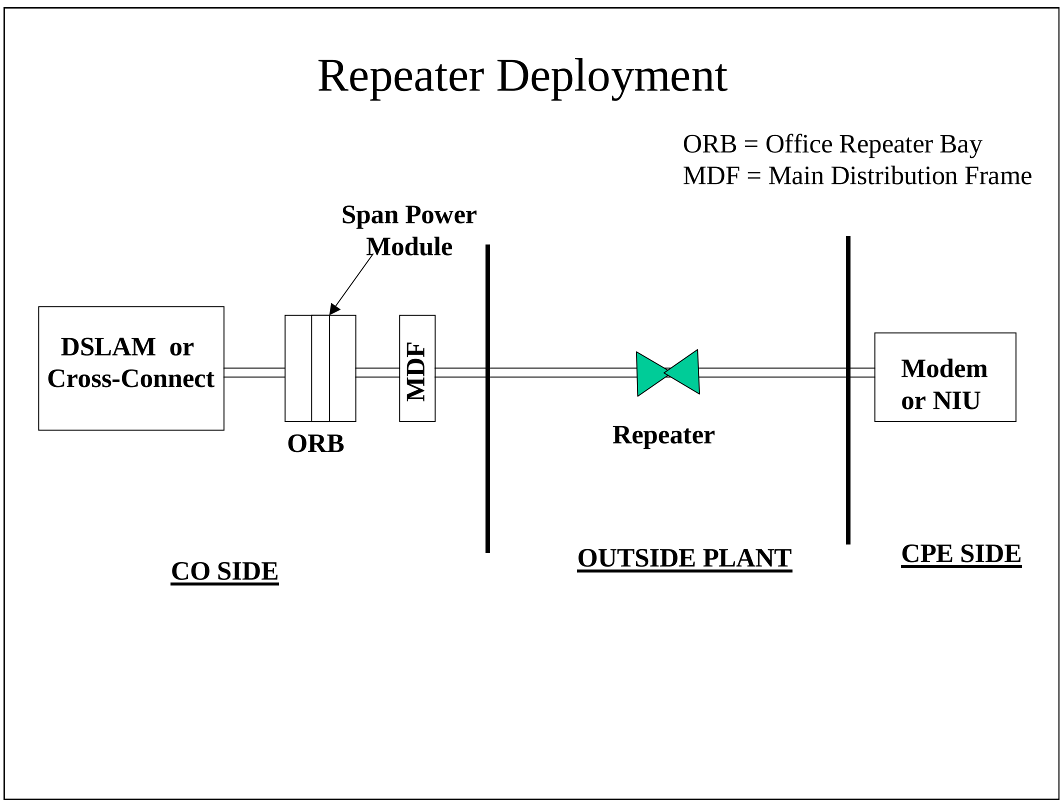


Figure 5.3 – Typical DSL Repeater Installation

5.2.2 Advantages

The most obvious advantage of providing regenerators for DSL technologies is to provide extended range. The extended range directly affects coverage area of a service provider. As an example, use of repeaters allows a service provider to extend the reach of a DSL technology by 100%. However, considering this extended range increases the radius of the coverage area, the area of coverage increases by 300%. This technique is of greatest advantage for delivering service to low-density clusters of customers on a per-line implementation basis, and is complimentary to other high concentration techniques in this document. The figure below depicts the gain in coverage resulting from the use of repeaters.

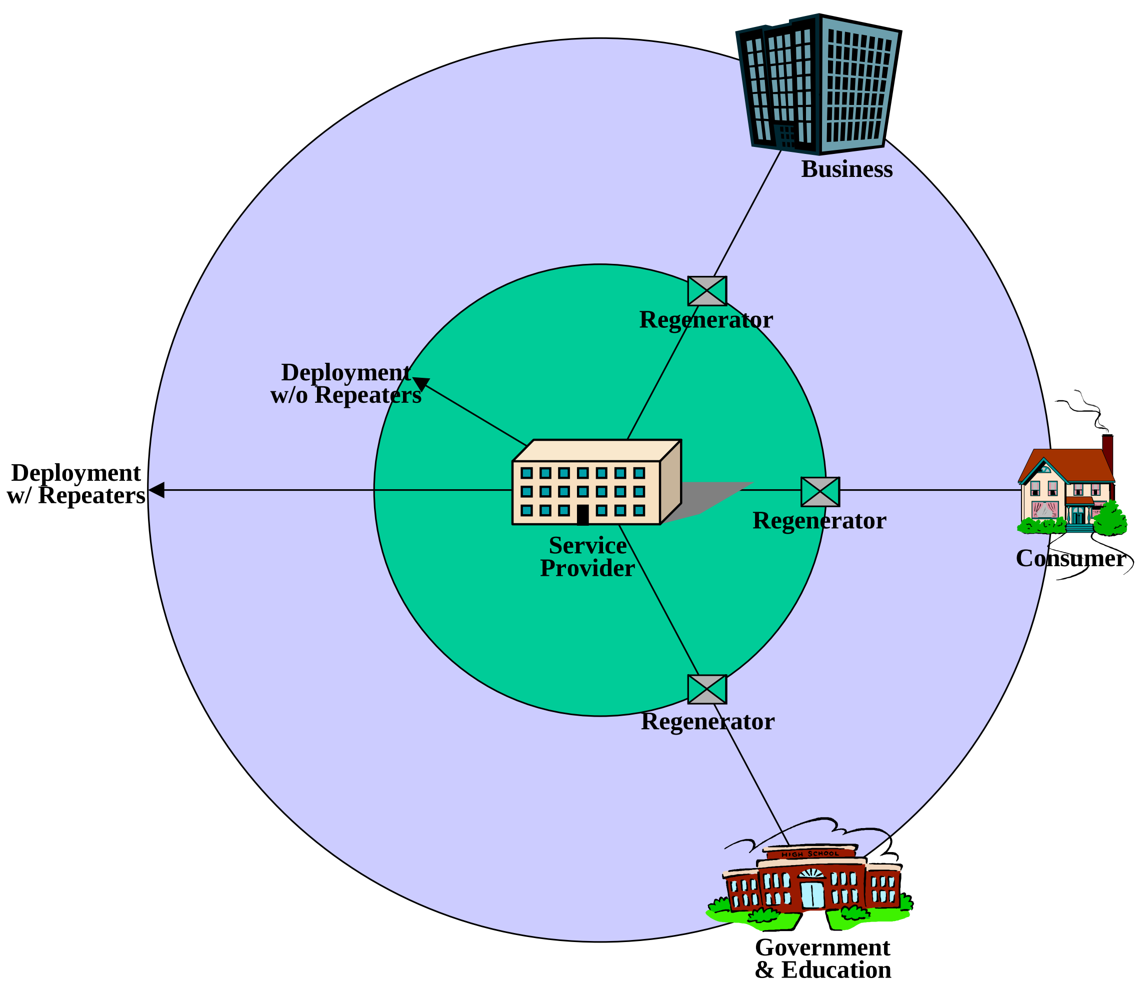


Figure 5.4 - Gain in Coverage Area using Repeaters

5.2.3 Implementation/Deployment Issues

The repeater technique requires insertion of an active element in the local loop plant. Deployment methods and procedures are consistent for most repeater installations. The only deployment criteria that varies significantly is the distance between elements in a repeatered circuit. Unfortunately, loop plant deployment presents challenges ranging from physical deployment to spectral compatibility.

- **Repeater Housings** - Repeaters must be deployed in environmentally hardened, pressurized housings to prevent the elements of nature from affecting the operation of the regenerators. These housings are typically either metallic domed enclosures or composite chamber-type housings located in man-holes or mounted on telephone poles. Deployment of the housings is costly and time consuming.

- **Temperature** - Even though repeaters are deployed in environmentally hardened housings, they still must operate over a wide temperature range. Regenerators can see temperatures that range from sub-0^0F up to 120^0F. Adding in the affects of solar loading on repeater housings, operational temperatures for regenerators easily exceed 150^0F. Care must be taken in repeater design to assure performance and reliability over a wide temperature range.

- **Span Power** - Power must be provided to repeaters via the copper facility that they are attached to. The first problem is the exposure of the service provider's technicians to high voltages on the copper facilities. In some applications, the differential voltages applied to the cable pairs exceed 200 Volts DC. A secondary problem with span powering is the application of positive DC voltages to the copper facility that can cause an electrolysis effect that can potentially degrade the performance of the copper facility.

- **Spectral Compatibility** - When repeatered technologies are deployed in the same binder group as non-repeatered technologies, deployment guidelines must be determined to assure spectral compatibility. While T1.417 (the recently approved Committee T1 Spectrum Management Standard) does not define guidelines for spectral compatibility for repeaters or regenerators, the tools are in the standard to perform such an analysis (Annex L). Specific guidelines for analysis of repeaters and regenerators are a subject of continued study under Committee T1's Spectral Compatibility Project.

5.2.4 Operational Issues

There are several "outside plant" operational issues worth noting for repeaters.

- **Installation** - As repeaters are installed in the outside loop plant, the added cost and logistical complexity of a "truck roll" is required to accomplish installation.

- **Troubleshooting** - Troubleshooting and fault isolation can be accomplished through diagnostic modes implemented in modern repeatered systems. Unfortunately, some repeatered systems lack adequate troubleshooting and fault isolation techniques contributing to significant delays in resolving customer troubles.

- **Repair** - A costly “truck roll” is required for repair/replacement of repeaters. Further, locating the correct repeater housing can be a challenge if adequate record keeping has not been maintained.

5.2.5 Network Management Issues

While it is true that repeaters pose significant operational issues, there have been significant efforts to address operational problems. One such effort is the advent of “intelligent repeaters.” Intelligent repeaters allow the isolation of troubles in a repeatered span by allowing each repeater to be addressed individually. Each element in the network then becomes capable of performing diagnostics and performance monitoring. This allows easy isolation of troubles. Today, T1, DDS, ISDN and HDSL all have intelligent regenerators available.

6.0 New Technologies

DSL deployment includes different flavors of DSL technologies whether based on public standards or proprietary. Symmetric rates DSL modems (e.g., HDSL, HDSL2, SDSL, SHDSL) primarily address the business market while the asymmetric rates DSL modems (or ADSL modems) primarily address the residential market. The majority of the current DSL modem deployment in residential market is based on the ANSI T1.413, and ITU-T Recommendations G.992.1 and G.992.2 ADSL modems. As the residential deployment is increasing, it is becoming clearer that further improving the reach of the existing ADSL technology would most benefit the rapid deployment of the DSL technology. In the business market, the DSL modems are typically based on HDSL1, HDSL2, and SDSL-2B1Q. The main issues of symmetric service deployment are spectral compatibility of these technologies with the ADSL modems and their reach performance beyond CSA coverage.

In the interest of deploying DSL Anywhere, there is a need for further improvement in the reach capabilities of both symmetric and asymmetric DSL modems. This section provides descriptions of new technology solutions that enhance reach capabilities of the DSL modems:

– **Improved ADSL**

ANSI T1.413, and ITU-T Recommendations G.992.1 and G.992.2 based ADSL modems describe an asymmetric transmission method for data transport in the access networks. These modems are typically capable of supporting downstream user data rates in the range of 32 kbit/s to 8000 kbit/ and upstream user data rates in the range of 32 kbit/s to 800 kbps in increments of 32 kbit/s using a Digital Multi Tone line code. The rate supported on a given loop is a function of distance. User data rates decrease as loop length increases. Many new techniques are under discussion for improving ADSL reach and data throughput. Among them, advanced coding and crosstalk cancellation are good examples.

– **G.shdsl-Single-pair High-speed Digital Subscriber Line (now formally known as ITU-T Recommendation G.991.2)**

Recently approved new ITU standard for Single-pair High-speed Digital Subscriber Line (SHDSL) Transceivers Recommendation G.991.2 describes a symmetric transmission method for data transport in the access networks. G.991.2 transceivers are capable of supporting selected symmetric user data rates in the range of 192 kbit/s to 2 312 kbit/s in increments of 8 kbit/s using a Trellis Coded Pulse Amplitude Modulation (TC-PAM) line code. G.991.2 modems can be configured to operate at longer reach than most of the exiting symmetric DSL technologies while maintaining spectrum compatibility with the ADSL modems.

In the following we explore in detail the implementations and reach advantages, which may help service providers cost-effectively, improve deployment of *DSL Anywhere*.

6.1 ADSL-Future Enhancements

6.1.1 Description of Technique

There are two major thrust to improve 2nd generation ADSL modems over the 1st generation. First, enabling longer reach by providing for powerful forward error correction and using techniques such as crosstalk cancellation. Second, enabling more features and applications that fit well into the evolving architecture, such as, simultaneous support of voice and data, that increases the value of the ADSL modems and provide alternative deployment architectures that help increase the coverage of ADSL service.

ITU-T SG15/Q4 is currently considering proposals for powerful Turbo and Low Density Parity Check (LDPC) codes. Mandatory use of the Trellis code is also under consideration. These coding techniques should bring the modem capacity within few dBs of the theoretical capacity. In ADSL modems, the available modem speed is a function of the available transmit power, loop loss, noise and crosstalk, which determine the signal to noise ratio required to maintain an acceptable bit error ratio. For a particular loop and a given noise, there is a particular maximum capacity for an ADSL modem. The goal of the ADSL improvements is to achieve that limit. The other approach that can help increase the effective Signal to Noise Ratio (SNR), and thus the reach, is crosstalk cancellation. In the following we illustrate the potential impact of the improved ADSL modems using these new techniques based on a theoretical simulation of the ADSL modems on a 26 AWG loop and 24 ISDN crosstalk disturbers with 6 dB performance margin.

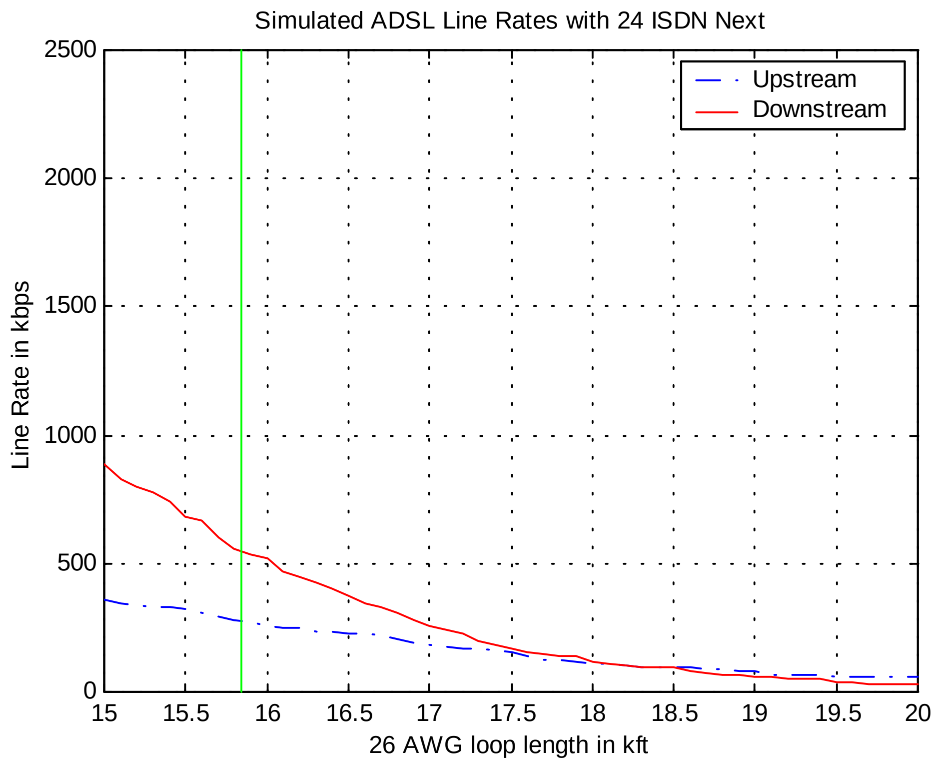


Figure 6.1 – Rate/Reach curve

Figure 6.1 shows a typical ADSL modem rate reach curve for a 26 AWG loop with 6dB performance margin and 3 dB coding gain with 24 ISDN crosstalk disturbers. At 3 miles, the line rates that can be supported are 560 kbps downstream and 276 kbps upstream.

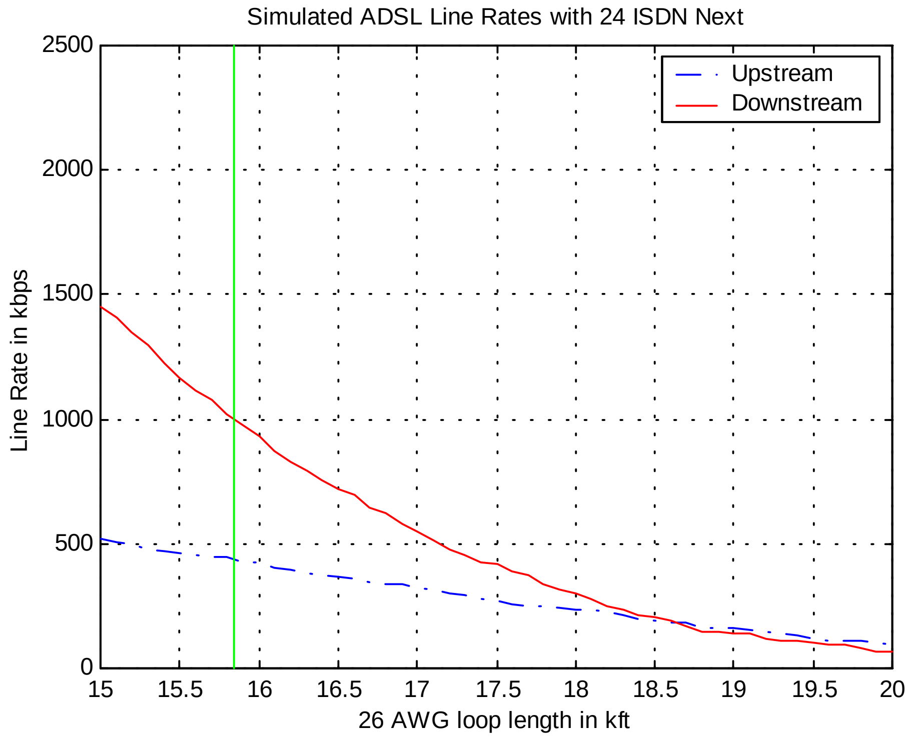


Figure 6.2 – Rate/Reach curve with 8db coding gain

Figure 6.2 shows the same with 8 dB coding gain. Additional 5 dB coding gain corresponds to a reach increase of about 1.1 kft. Figure 6.3 shows a typical ADSL modem rate reach curve for a 26 AWG loop with 6dB performance margin and 8 dB coding gain with 24 ISDN crosstalk disturbers and assuming an average of 5dB crosstalk cancellation. This corresponds to a reach increase of another 1.2 kft. Together, FEC and crosstalk cancellation can provide another 2.3 kft loop reach increase for the case under consideration. Alternatively, the line rates at 3 miles can be improved from 560 kbps downstream and 276 kbps upstream to 1560 kbps downstream and 596 kbps upstream. Under different crosstalk combinations and loop types the gains may not exactly be the same as reported here, but they are expected to be close to the numbers mentioned here in most scenarios of practical interest.

A number of other smaller improvements are also going to contribute to the reach of the ADSL. These are more efficient framing and the use of 1 bit constellation.

The performance enhancement techniques help increase the ADSL service coverage to about 99% of the urban customers. There are however other scenarios, which require significant increase in reach and is not physically realizable from these modems. This would require new deployment architecture as a solution, some of which have been discussed in this paper. To facilitate these architectures and to complement the current service, improved ADSL is also considering the use of an All Digital Mode operation and simultaneous support of channelized voice and data. Together it removes the need for

POTS splitters while facilitating Broadband Digital Loop Carriers and reuse of the existing communication facilities.

6.1.2 Advantages

Improved ADSL would increase the reach at which ADSL modems work. This should increase the coverage of the ADSL service. For the current coverage, it would increase the rate at which customers are connected. Moreover, new features should facilitate the DLC deployment scenarios.

6.1.3 Implementation/Deployment Issues

The main issue related to the ADSL improvement is the implementation complexity as all these techniques are computationally intensive. Interoperability of the 2nd generation modems would also require some time.

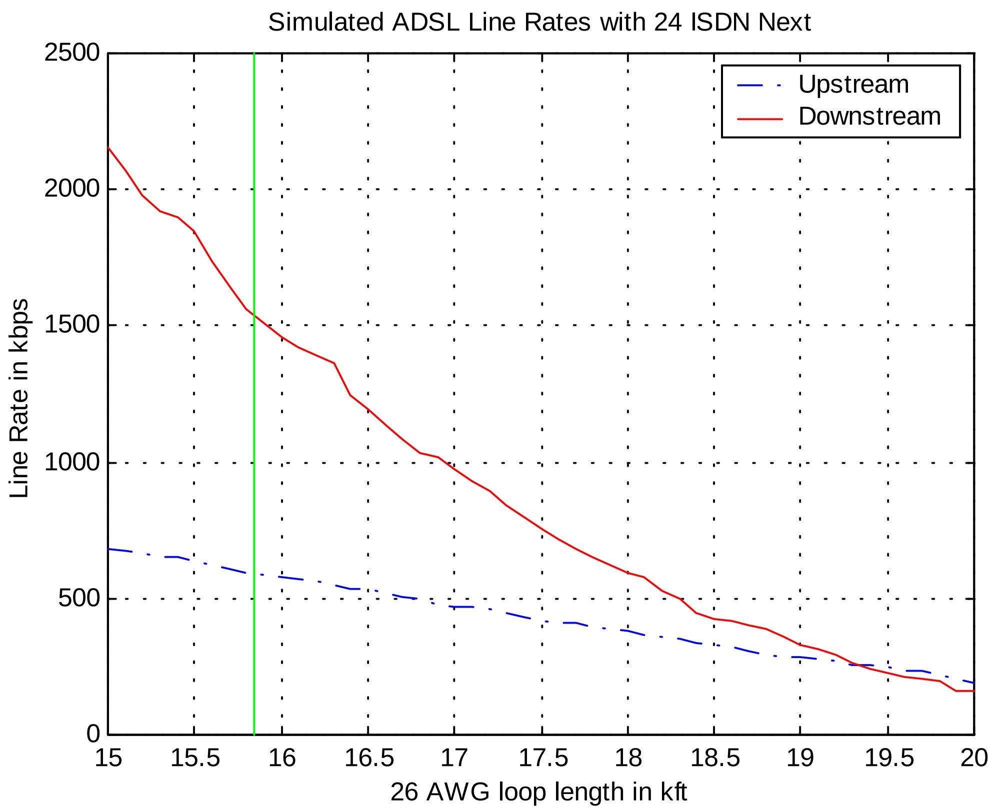


Figure 6.3 – Rate/Reach curve with 8db coding gain and 5db crosstalk cancellation

6.2 G.SHDSL

6.2.1 Description of Technique

G.991.2 is an International Telecommunication Union (ITU) Recommendation that specifies a technique for high speed, symmetric Digital Subscriber Line (DSL) delivery over a single copper pair at rates between 192kbps and 2.312Mbps. G.991.2 was developed as an encompassing technology that addresses the key features and benefits of other DSL technologies, whether proprietary or standard, to achieve interoperability throughout the DSL world. G.991.2 is significant in that it addresses rate/range adaptability, spectral compatibility, impairment tolerance, and high-speed symmetric deployment for business-based applications such as multiple voice line delivery, Internet access and remote LAN access. G.991.2 represents the convergence of many traditional DSL technologies into a single, internationally recognized industry standard.

6.2.2 Advantages

Trellis Coded Pulse Amplitude Modulation (TC PAM) has been chosen as the modulation technique for G.991.2. TC PAM has been used extensively in recent years as the basis for 2-wire repeaterless 64k data and ISDN deployment in the Incumbent Local Exchange Carrier (ILEC) networks. The recently standardized HDSL2 (ANSI document number T1.418-2000) used in 2-wire DS1 delivery has been widely accepted because of its copper pair savings and uses TC PAM as its modulation technique. HDSL2 is specified for a single rate for 1.544Mbps delivery, whereas G.991.2 specifies the wide range of data rates and ranges.

TC PAM was chosen as the basis for G.991.2 due to the low complexity of the algorithms and the low latency required for voice traffic. The use of Trellis Coding provides an additional “coding gain” that improves the performance of the digital signal in the presence of interference. The resulting higher level of performance allows the deployment distance to be increased without sacrificing any of the safety “margin” required for practical, real-world implementation. Compared to SDSL-2B1Q, TC PAM is more spectrally friendly, ensuring compatibility with other DSL-based services such as ADSL.

The TC PAM characteristics that make G.991.2 attractive for spectral compatibility, the use of narrower frequencies for transmission, along with the coding gain from the Trellis Coding allow better performance for G.991.2. Figure 6.4 shows the performance improvements of G.991.2 over SDSL 2B1Q.

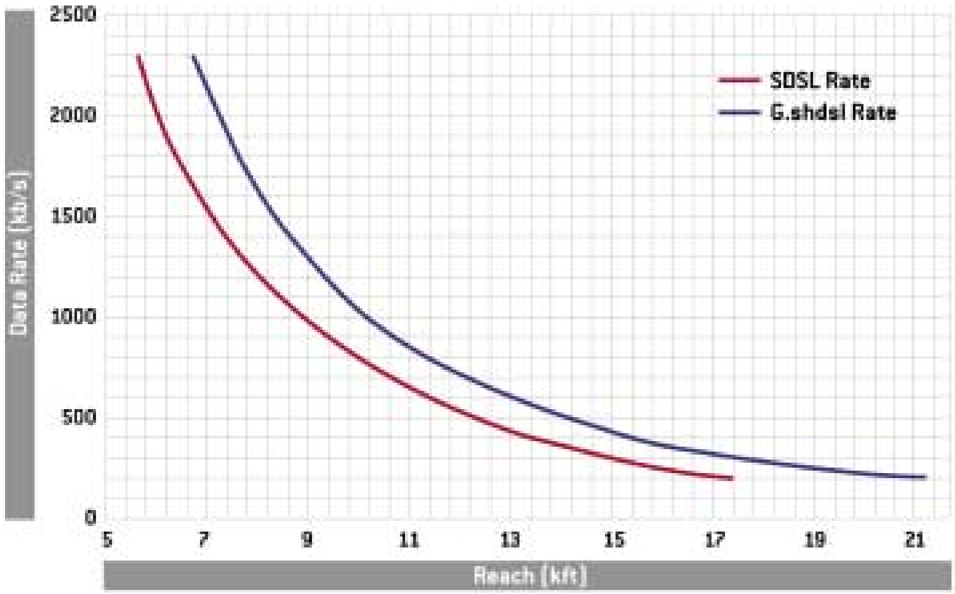


Figure 6.4 - G.991.2 (G.shdsl) vs. SDSL-2B1Q

Figure 6.4 depicts the 1% worst case performance in a 49 disturber Self NEXT environment on 26AWG copper. In other words, performance is expected to be better than shown in 99% of the deployments. For a given rate, G.991.2 increases range by 15% to 20%. For a given range, G.991.2 increases rate performance by 35% to 45% over SDSL-2B1Q.

Doing a simple comparison of coverage area, the radius of the coverage area for G.991.2 versus 2B1Q SDSL is between 15% and 20% greater. Simple mathematics show that the coverage area expands by 32% to 44% by using G.991.2 versus 2B1Q SDSL.

6.2.3 Implementation/Deployment Issues

G.991.2 is also spectrally compatible with other loop technologies. TC PAM is particularly attractive for its spectral characteristics. When deployed in the same binder group or cable with other services, its narrower frequency band reduces the possibility for interference, or crosstalk, with services such as ADSL. Figure 6.5 illustrates the “spectrally friendly” nature of a G.991.2 implementation compared to the traditional SDSL-2B1Q.

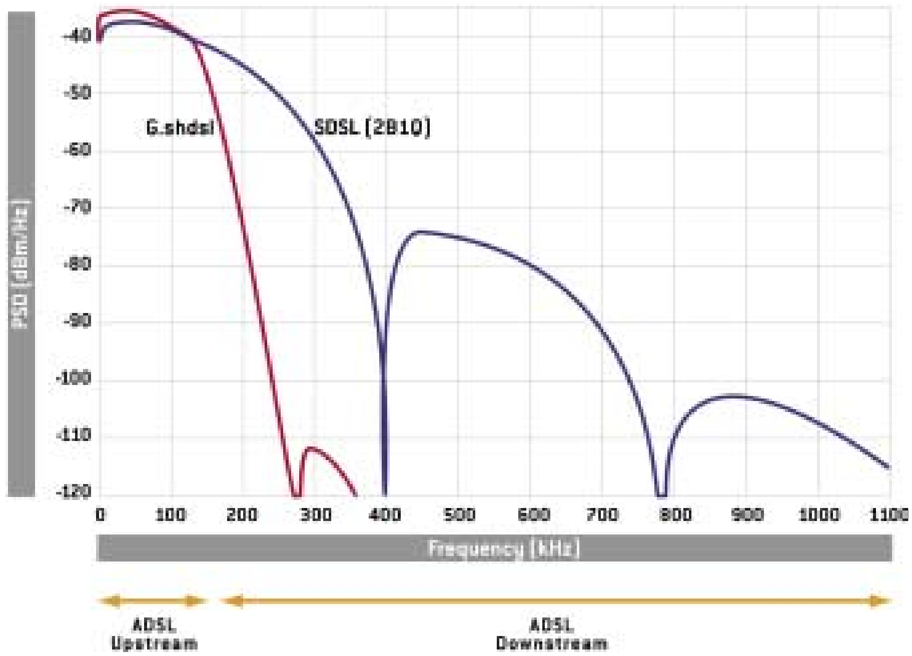


Figure 6.5 - PSD of G.991.2 and SDSL-2B1Q at 768kbps

This diagram shows the PSDs associated with G.991.2 and SDSL-2B1Q at a 768kbps data rate. PSD is a representation of the energy associated with a signal across a band of frequencies. Likewise, it is indicative of the potential for interference with ADSL in its upstream and downstream directions. In the downstream direction there is little difference in the effect either technology may have on the transmitted ADSL signal. However, the downstream, or high bandwidth direction, of ADSL may be significantly affected by SDSL-2B1Q and is affected very little by G.991.2.

The University of New Hampshire's Interoperability Labs is sponsoring a G.shdsl Consortium to bring together vendors from the G.991.2 community to conduct interoperability testing. The first scheduled G.shdsl plugfest is the week of November 6th, 2000.

6.2.4 Operational Issues

Interoperability is an added benefit of the ITU-T Recommendation G.991.2. As with HDSL2, specific requirements are defined for G.991.2 equipment and its deployment. Early experience with HDSL2 equipment has shown that interoperability with good performance is being achieved between standards compliant implementations. Since many of the implementation issues are the same with G.991.2, it is expected that high performing interoperable implementations will be available in a very short timeframe.

7.0 Alternative Solutions

7.1 Low Frequency DSL - Improved Reach Technology

7.1.1 Introduction

One proprietary method for extending loop reach is to design a totally new transceiver that has operation on all unloaded loops (loops without loading coils) as a requirement. This section discusses how this approach can be taken with Low Frequency DSL.

Use of Lowest Frequencies

The primary technical method for extending loop reach is to use the lowest frequency band possible. This is due to a basic "law of physics": (Refer to Figure 6.6) As loop length increases, low frequencies are attenuated less than high frequencies. Thus, at the receiver, low frequency signals are received at a much higher power level than high frequency signals.

Since noise and crosstalk are present on a line, the "SNR" (Signal to Noise Ratio) is better at the receiver for low frequencies.

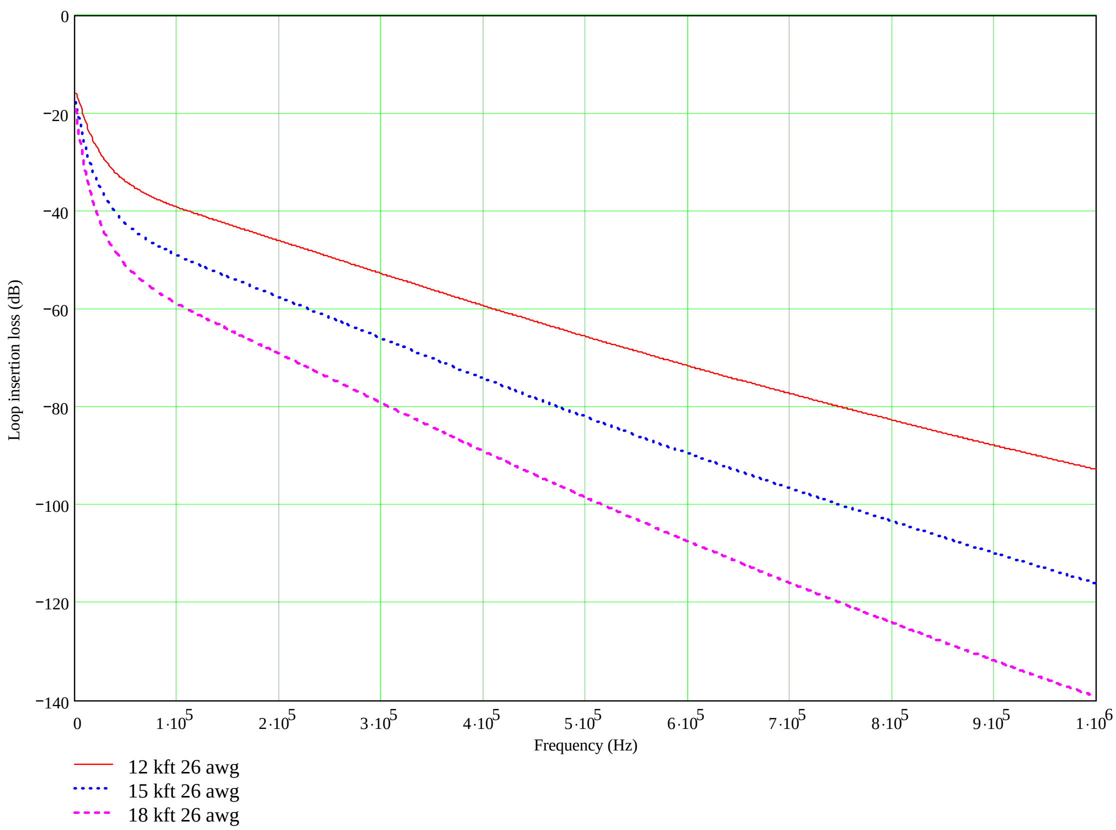


Figure 7.6: Attenuation of Signal vs. Loop Length and Frequency

Low Frequency DSL uses the lowest frequencies of any existing DSL modulation. The following graph shows the frequency band of Low Frequency DSL and the current ADSL standard:

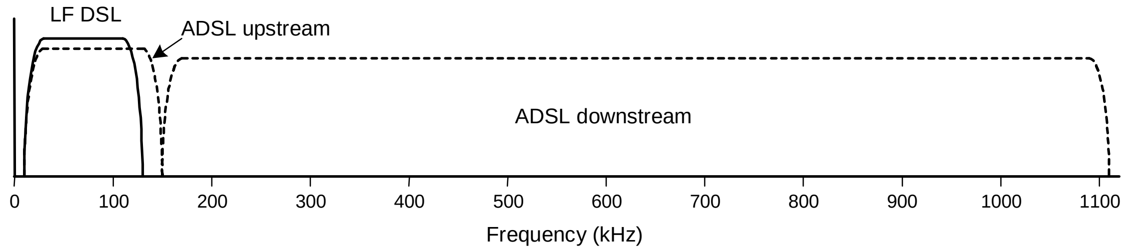


Figure 7.7: Low Frequency DSL vs. ADSL frequency usage

For Low Frequency DSL, both the downstream and upstream transmitters operate below the ADSL downstream band edge.

Comparing Figure 7.6 with Figure 7.7, it is apparent that Low Frequency DSL has significantly better SNR performance than ADSL on long loops.

Rate vs. Loop Reach

While the rate of Low Frequency DSL drops off in proportion to loop length, it still can achieve high speeds at long loop lengths. The following chart shows typical rates achievable by Low Frequency DSL up to 36k feet. Two test conditions are shown:

1. No disturbers
2. Four T1 disturbers (adjacent binder) plus a bridged tap

Note that these tests are based on 24 gauge loops. In actual practice, longer loops could be achieved with the use of lower gauge twisted pair (22 AWG and 19 AWG.)

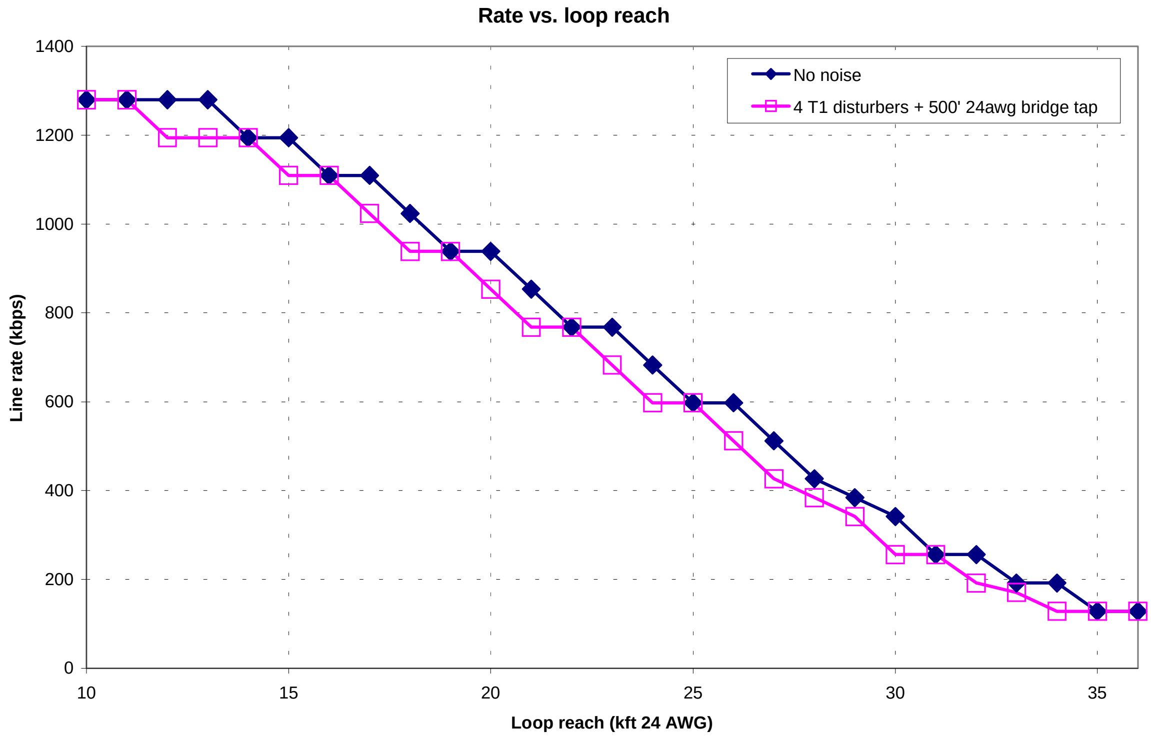


Figure 7.8: Rate vs. Loop Reach

Special Note: Since the graph above is based on wire gauges and noise models different from the other technologies in this paper, these values should not be directly compared with the other technologies.

7.3.2 Advantages

Low Frequency DSL works on local loops that do not have loading coils. It has been deployed in a number of installations with a high level of success on loops that significantly exceed ADSL reach capability limits.

Low Frequency DSL addresses many of the impairments typically found on local loops. While the impact of these impairments is greatest on long loops, they can often cause difficulties for some transceivers even on short loops:

Bridged taps

These exist on a high proportion of loops. Even short bridged taps can cause issues with modulations such as ADSL that use high frequencies. In particular, the most common bridged-taps -- lengths between 150 and 700 feet -- are the most damaging to ADSL performance. These bridged taps do not significantly impact the frequency band used by Low Frequency DSL

T1 and 56k DDS

Low frequency DSL has been demonstrated to be immune to T1 and 56K DDS disturbers in the same binders in both short and long loop deployments.

Upstream and Downstream in same low frequency band

In Low Frequency DSL, both upstream and downstream transmissions operate at the lowest frequencies. Therefore, the highest speed is supported in both directions. This allows Low Frequency DSL to support both symmetrical and asymmetrical operation at the longest reaches.

Line Sharing
Low Frequency DSL implementations generally can be deployed on line shared loops with existing baseband POTS.

Spectral Compatibility
Low Frequency DSL implementations meet the Spectral Compatibility Standard (T1.417)..

Operational Considerations:
No standards currently exist for low frequency DSL implementations.

7.3.3 Extra considerations; Rate vs. Loop Reach

While the rate of Low Frequency DSL drops off at longer loop lengths, it can still achieve high speeds at long loop lengths. The following chart shows rates typically achievable by Low Frequency DSL up to 30k feet.

The test results use “mixed gauge” wire that is typical of real world installations. The mixed gauge format conforms to Revised Resistance Design (RRD) rules and uses a gauge mix that has been publicly published on the web page of a major US RBOC.

Up to 15k feet from the Central Office, only 26-gauge wire is used. For 16k feet and greater, the following gauge mix is used:

k feet	26gauge	24gauge	22gauge
16	14.5	1.5	
17	13	4	
18	11.5	6.5	
19	9	10	
20	7.5	12.5	
21	6	15	
22	4	18	
23	2.5	20.5	
24	1	23	
25	0	24	1
26	0	22	4
27	0	20	7
28	0	18.5	9.5
29	0	17.5	11.5
30	0	15.5	14.5

The test results show five T1 AMI circuits are included in the same binder for impairments.

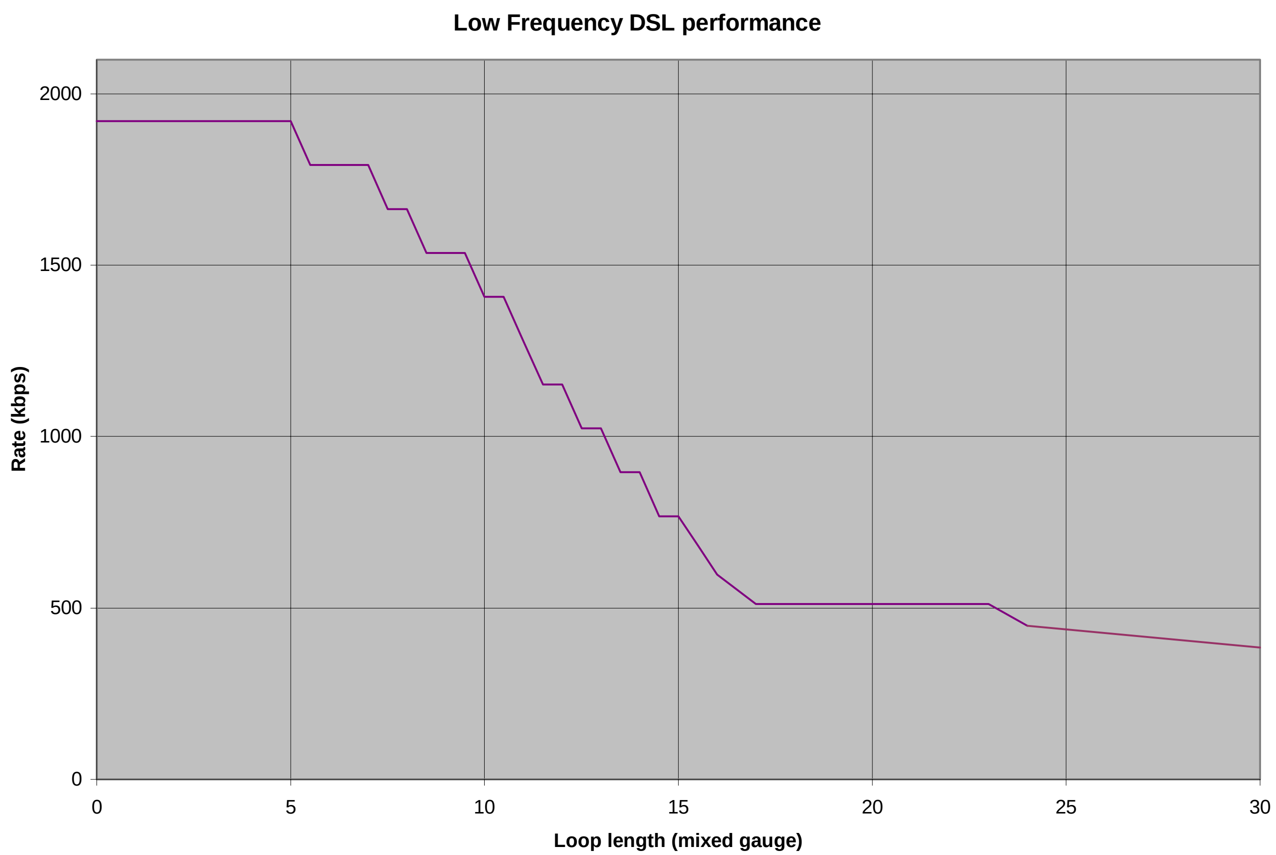


Figure 7.9: Rate vs. Loop Reach

Special Note: Since the graph above is based on wire gauges and noise models different from the other technologies in this paper, these values should not be directly compared with the other technologies.

8.0 Conclusion

The techniques discussed in this paper enable service providers to efficiently make DSL-based services available to nearly all customers. Some service providers have already introduced many of these techniques to provide service to a wider area. Furthermore, some of these techniques enable much higher bit-rate service to areas that were already served. As these DSL enhancements are widely adopted, the availability and capacity of DSL services will dramatically improve beyond the state of the industry, as it existed at the end of the year 2000.